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Lane, B. H., 1935. Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, Washington, D. C. (For sale by Superintendent of Documents, Washington, D. C., 25c.)

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APRIL 1952

RADIOACTIVITY OF OCEAN SEDIMENTS. VIII. RADIUM AND URANIUM CONTENT OF OCEAN AND RIVER WATERS

ELIZABETH RONA AND WILLIAM D. URRY

ABSTRACT. Some new determinations of the radium and uranium content of ocean and river waters are reported here and it appears possible to draw some tentative general conclusions concerning the distribution of the radioelements of the uranium-238 series in the hydrosphere from these measurements and the few reliable determinations reported in the literature. The conclusions are based on few data and are presented to indicate possible fruitful lines of future endeavor in this field and should not be construed as forming a completed general theory.

Variations of the radium content of ocean waters, both laterally and in depth, appear to be attributable to the presence of different water masses. Open ocean waters contain only about 16 per cent of the amount of radium that would be in radioactive equilibrium with the uranium content, a finding in agreement with the work of previous investigators on inshore waters. This departure from equilibrium is quantitatively the complement of the departure from equilibrium in presently deposited ocean sediments. Ocean waters lack also the ionium content required for equilibrium with the uranium content. A few measurements of the radium and uranium contents of river waters show that the departures from radioactive equilibrium are in the opposite direction from similar departures in ocean waters, and in this respect the relations between the radioelements in river waters are qualitatively the same as those in the ocean sediments.

INTRODUCTION

THE importance of relations between concentrations of radioelements in ocean water and bottom sediment in a general study of the radioactivity of ocean sediments has been discussed in an earlier paper of this series (Piggot and Urry, 1941).

The oceans and the bottom sediments constitute a relatively simple chemical and physical system by comparison with the system of the rocks and sediments comprising the continents. Oceanographers have successfully applied the principle of dynamic equilibrium to describe the properties of the oceans.

These properties, being the properties of a moderately well-mixed system, are, in general, remarkably alike from pole to pole, but differ sufficiently in detail to enable identification of characteristic water masses and to result in different types of sediments. The well-known relations existing between the elements in a radioactive series made these radioelements peculiarly adapted to tracing some of the physical, chemical, and biological processes responsible for the character of the different water masses and the various types of bottom sediments, in addition to providing a method of determining the age and rate of deposition of the sediments (Piggot and Urry, 1942*a*; Urry, 1948). A lack of data prevented any quantitative study of these problems at the time of the earlier paper (Piggot and Urry, 1941). Since then, a number of determinations of uranium, ionium, and radium contents of ocean sediments have been made and reported (Piggot and Urry, 1942*a*,*b*; Urry, 1949). This paper presents the measurements of the radium and uranium content of open ocean waters, for which no reliable radium values were available earlier.

Determinations of the radium content of ocean water date back to the measurements of Eve in 1909. Evans, Kip, and Moberg in 1938 demonstrated a serious error in all previous determinations and offered convincing evidence that earlier values for the radium content of ocean waters were much too high, often by a factor exceeding a hundred. Results of further measurements, reported by Pettersson and Rona (Föyn, Karlik, Pettersson, and Rona, 1939, Part II) soon thereafter, confirmed the work of Evans, Kip, and Moberg. The present determinations, insofar as they are comparable, agree favorably with the values reported by both groups.

Measurements of the uranium content of ocean water were first made by Hernegger and Karlik (1935) and were followed by a series of determinations by Karlik in 1939.[1]

The authors undertook the investigation reported here because no samples measured by the above two groups were representative of the open ocean, with the exception of a few specimens measured by Karlik (Föyn, Karlik, Pettersson, and Rona, 1939, Part I) for their uranium content. The

[1] Results of more recent uranium determinations in sea water samples came to our attention after the completion of this paper. G. Koczy, 1950. *Further uranium determinations in sea water samples.* Sitzb. d. Acad. d. Wiss. Wein. 158, 113.

samples studied by Evans, Kip, and Moberg were, with a single exception, all from inshore waters of the West Coast of the United States. The samples studied by Pettersson's group were from the waters surrounding Sweden, several being of very low salinity, and, as such, of peculiar interest by comparison. Fig. 1 shows the locations of six of the seven stations occupied by the *Atlantis* in sampling the ocean waters to depths of 2000 meters for the present work. While these waters were taken beyond the limits of the continental shelf,

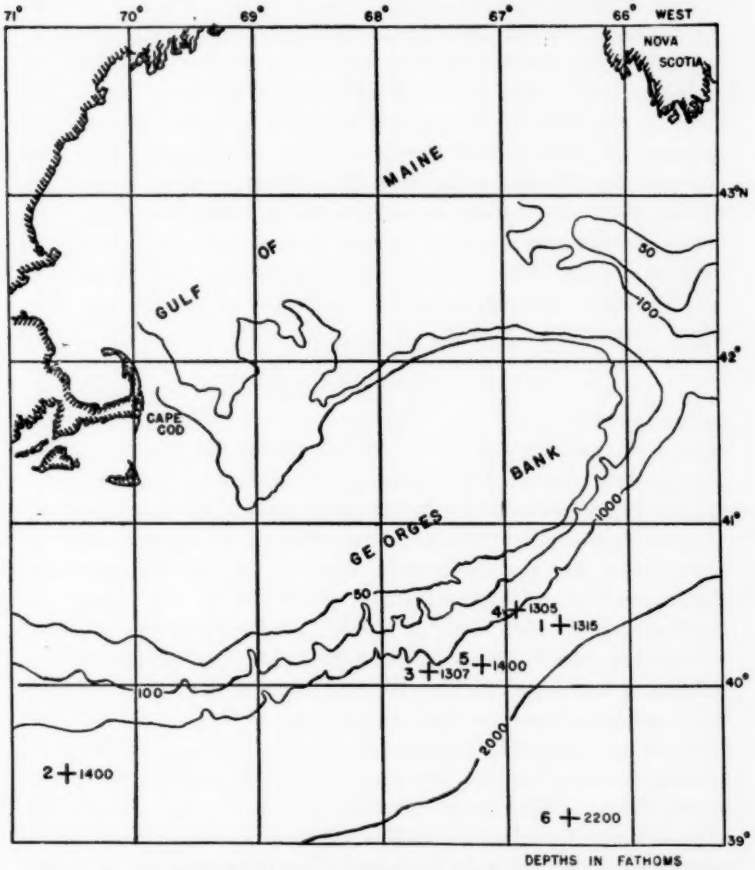

Fig. 1. Locations of stations occupied by the *Atlantis* in securing samples for the measurements of the radium and uranium content of ocean water.

it would be desirable in the future to extend the sampling to locations over the abyssal deeps.

SAMPLES

The sea-water samples were collected in the summer of 1941 by the crew of the ketch *Atlantis* with the use of a deep-water sampler for large samples designed by Ewing. The samples were stored on board in glass carboys or beechwood barrels with the immediate addition of 2 cc. of distilled hydrochloric acid per liter of water to prevent adsorption and precipitation of the radium. The containers had been rinsed several times previously with hot hydrochloric acid and distilled water to remove any traces of radium and uranium that might later be dissolved by the acidulated water samples. The radium was coprecipitated with barium sulfate immediately upon return of the *Atlantis* to Woods Hole, Mass., where this phase of the work was conducted at the Marine Biological Laboratory. Measurements of the radium and uranium content were carried out in 1941-1942 at the Geophysical Laboratory of the Carnegie Institution of Washington and at Trinity College, Washington, D. C.

METHOD OF RADIUM ANALYSIS

Sea water, weight for weight, is more than 10,000 times poorer in radium and 3,000 times poorer in uranium than the igneous rocks. Therefore, great care must be exercised in all manipulations, and the determinations are exacting under the best of conditions even though it is far easier to concentrate the radioelements from a solution like sea water than it is from a large quantity of rock.

Evans, Kip, and Moberg (1938) preferred to release and collect the radon in equilibrium with the radium by reflux-boiling and nitrogen displacement in samples of about 1600 cc. This method possesses the distinct advantages of requiring little or no preparation and of offering little possibility of contamination, but the sample is small and difficulty is encountered in determining a small ionization current or low rate of alpha-particle emission against a much larger and practically irreducible background. The measurements of these authors were, therefore, accompanied by errors of ± 25 to 100 per cent for many of their samples. These errors arise

from the inherent statistical fluctuations in disintegration of the radioelements and cannot reasonably be reduced except by taking much larger samples. This would present great difficulty in complete removal of the radon. For this reason, and because the measurements of Evans, Kip, and Moberg, of Pettersson and Rona, and of our preliminary determinations were in good agreement, the method of concentrating the radium employed by Pettersson and Rona (1939, Part II) was used. This consisted of coprecipitating the radium with barium sulfate from samples of 30 to 60 liters of water by adding about two grams of barium chloride dihydrate per 30 liters. Such an amount is sufficient, according to Pettersson and Rona, to remove at least 96 per cent of the radium from the water. More than sufficient sulfate is present in sea water to precipitate such amounts of barium. The barium sulfate was then converted to the carbonate, which was dissolved in hydrochloric acid. The resulting solution of about 100 cc. was sealed in a suitably designed storage flask described by Urry and Piggot (1941, p. 633). After a thirty-day period of storage, following which the radon was in equilibrium with the radium, the radon was removed by reflux-boiling and nitrogen displacement and measured in the ionization chambers described by Urry and Piggot.

A number of corrections are necessary to derive the radium content of the water sample, Ra_w, from the measured radium content of the final solution, Ra_m. Quantitative recovery of the precipitate from such large quantities of water was impracticable and was between 80 and 90 per cent complete. It was assumed that the degree of recovery of the radium was in proportion to the ratio (Ba_1/Ba_a) of the barium sulfate recovered and calculated as $BaCl_2.2H_2O$ to the weighed amount of $BaCl_2.2H_2O$ added to the water sample. There was a further loss of up to 10 per cent of the barium in the conversion of the sulfate to the carbonate. Consequently, following completion of the radium measurements, all the solutions were analyzed for barium, which was expressed as $BaCl_2.2H_2O$ and denoted by Ba_2. The assumption of a sufficiently close approximation to the proportionality between the recovery of barium and radium was verified by measurements of three successive precipitations in two samples of river water.

If the radium content of the barium chloride is denoted by

Ra_{B_a}, the radium content of the water sample just prior to precipitation is given by $Ba_a \times Ra_{B_a} + Ra_w$ and the collected precipitate contains

$$(Ba_1/Ba_a)\ (Ba_aRa_{B_a} + Ra_w)$$

and the measured radium content of the final solution is given by

$$Ra_m = (Ba_2/Ba_1)\ [(Ba_1/Ba_a)\ (Ba_aRa_{B_a} + Ra_w) + Ra_o] \quad (1)$$

where Ra_o is the total radium content of the chemicals and water used in converting the sulfate to carbonate. The water and hydrochloric acid used were specially distilled over barium chloride and found to contain the order of 0.03×10^{-12} g. Ra per 100 cc. Thus, with the small quantities of these reagents employed, contamination from these two sources was wholly negligible.

Rearranging equation 1:

$$Ra_w = (Ba_a/Ba_2)(Ra_m - Ba_2Ra_{B_a} - Ra_oBa_2/Ba_1) \quad (2)$$

A single preparation of $BaCl_2.2H_2O$ was used for all the determinations. The radium content Ra_{B_a} was 0.81×10^{-12} g. per g., which is higher than desirable but no better preparation was available at the time.[2] Accordingly, about two-thirds of the measured radium was attributable to the water sample. Control experiments in which the complete process was carried out without the water sample gave values of Ra_m that could be substituted in equation 2 for $Ra_w = 0$ to give Ra_o. The value of Ra_o was found to be 0.27×10^{-12} g. radium for the standardized amounts of the various chemicals employed in the conversion of barium sulfate to carbonate and to chloride.

The root mean square probable error of the radium determinations is $\pm\ 0.02 \times 10^{-16}$ g. radium per cc. The duration of the recording of the ionization current was adjusted for each measurement to provide at least this accuracy. All the present radium measurements were based on the standard radium solution containing 10^{-11} g. radium prepared by the National Bureau of Standards.

METHOD OF URANIUM ANALYSIS

For each uranium determination, seven liters of water were saved from the total sample so that uranium and radium

[2] By a series of fractional precipitations of barium chromate, a preparation of $BaCl_2.2H_2O$ was later obtained with a radium content of only 0.02×10^{-12} g. radium per g., starting with barium chloride containing approximately 1×10^{-12} g. radium per g.

measurements could be carried out on the same sounding. Uranium was determined by a method developed by Hernegger (1933) which depends upon the ultraviolet fluorescence of fused sodium fluoride containing traces of uranium. Full details of the application of this method to the determination of uranium in sea water have been described by Hernegger and Karlik (1935). The uranium is separated by triple coprecipitation with a few milligrams of iron as hydroxide. The collected precipitates are dissolved and reprecipitated and again dissolved, after which the iron is separated as carbonate. The filtrate containing the uranium is dried, the ammonium salts dissociated, and silica removed with hydrofluoric acid. The very small residue is mixed with an exact standard weight of sodium fluoride in water containing a few drops of hydrofluoric acid, and is dried, ground, and melted into a number of standard-sized beads of 2 mm. diameter on platinum loops. The sample is subjected to further mixing if the spectra of ten to twenty beads fail to exhibit homogeneity. Similar beads, containing known amounts of uranium, are prepared from standard solutions of uranium added directly to the standard weight of sodium fluoride.

The optical measurements of the intensity of the fluorescence spectra of uranium samples were performed in the following improved manner. The bands at 5570 and 5340 Å were used for comparisons and were photographed with a very fast spectograph on superpanchromatic press film. The following method of calibration was adopted: Replacing the slit with a step diaphragm, calibration marks were put on each film, and the spectra of the beads were photographed on the same film. The densities of the calibration marks as well as those of the samples were measured with a photoelectric densitometer, and the ratios of the steps were plotted against their densities. In a second curve, intensities of the standard samples were plotted against their densities. From these plots, a working curve giving ratios of the steps against uranium concentration was constructed. The uranium content of the unknown sample was read from this curve.

For each sample, the optical measurements were made on three occasions for each of three or more beads, with a mean deviation of 2 to 5 per cent.

This method can be used for quantities of uranium between

10^{-5} and 10^{-10} gram per bead. The root mean square probable error of the present measurements was between 0.02 and 0.05 x 10^{-9} g. uranium per cc.

REPRODUCIBILITY MEASUREMENTS

In order to investigate the reproducibility of the chemical procedures for the radium determinations, two of the original water samples were divided and treated independently. The correction for the incomplete recovery of barium sulfate was anomalously large for the (a) portion of the sample from station 4 at 200 meters, which may explain the discrepancy between the results for this divided sample given in table 1.

TABLE 1

Degree of Reproducibility Measurements of the Radium Content of Water Samples in 10^{-16} g. Radium per cc.

Sample			*Radium content*
		Divided Water Samples	
Station 4	200 meters	(a)	0.25 ± 0.02
		(b)	0.40 ± 0.02
Station 4	485 meters	(a)	0.33 ± 0.02
		(b)	0.31 ± 0.015
		Divided Barium Sulfate Samples	
Station 1	1200 meters	(solution)	0.25 ± 0.03
		(fusion)	0.28 ± 0.04
Hudson River water		(solution)	0.37
		(fusion)	0.38
		Successive Measurements	
Station 1	0 meters	(1)	0.50 ± 0.02
		(2)	0.41 ± 0.02
Station 1	200 meters	(1)	0.31 ± 0.02
		(2)	0.34 ± 0.02
Station 3	0 meters	(1)	0.48 ± 0.03
		(2)	0.47 ± 0.03

In order to determine the efficiency of removal of radon from the final preparations, two samples were divided at the barium sulfate stage, one-half being subjected to the conversion to chloride followed by storage in solution as previously described, the other half being measured in the manner described by Urry and Piggot (1941) for solid samples using the vacuum fusion furnace. The agreement is noted in table 1.

The reproducibility of the ionization measurements and the removal of radon from the solutions was investigated by re-

peating the measurements following a second period of storage for 30 days, with the results given in table 1.

The reproducibility of the chemical procedures and optical measurements used in the determination of the uranium content was tested by dividing the portion of the water sample from station 5 at 2 meters reserved for the uranium determination into two parts and treating each separately. The results obtained were 0.73 ± 0.05 and $0.78 \pm 0.05 \times 10^{-9}$ g. uranium per cc.

RESULTS

Radium.—Table 2 presents the results of the measurements of the radium and uranium content of ocean water from

TABLE 2

Radium and Uranium Content of Ocean Waters

Sample depth meters	Temp. °C.	Salinity o/oo	Ra in 10^{-16} g/cc	U in 10^{-9} g/cc	Ra_U in 10^{-16}* g/cc	Ra / Ra_U
Station 1. May 31, 1941. Lat. 40° 22' N. Long. 66° 34' W. Bottom at 2405 meters.						
0	14.0	33.0	0.46	—	—	—
200	10.0	35.2	0.33	0.84	2.93	0.11
700	4.3	34.97	0.24	—	—	—
1200	3.5	34.94	0.25	—	—	—
Station 2. June 20, 1941. Lat. 39° 26' N. Long. 70° 34' W. Bottom at 2560 meters.						
0	—	—	0.27	—	—	—
340	6.03	35.05	0.13	—	—	—
630	4.50	35.00	0.07	—	—	—
1100	3.94	34.96	0.30	—	—	—
Station 3. July 16, 1941. Lat. 40° 05' N. Long. 67° 38' W. Bottom at 2390 meters.						
0	23.94	35.4	0.47	—	—	—
2070	3.47	34.96	0.34	0.38	1.32	0.26
Station 4. July 15, 1941. Lat. 40° 28' N. Long. 66° 56' W. Bottom at 2390 meters.						
200	10.54	35.25	0.33	0.92	3.21	0.10
485	4.63	34.98	0.32	0.33	1.15	0.28
970	4.00	34.97	0.36	—	—	—
Station 5. Aug. 8, 1941. Lat. 40° 07' N. Long. 67° 12' W. Bottom at 2560 meters.						
2	24.70	34.79	0.58	0.75	2.62	0.22
495	6.40	35.06	0.14	0.30	1.05	0.13
985	3.98	34.99	0.35	0.86	3.00	0.12
1980	3.34	34.77	0.39	0.75	2.62	0.15
Station 6. Aug. 9, 1941. Lat. 39° 10' N. Long. 66° 31' W. Bottom at 4020 meters.						
2	26.7	35.90	0.37	0.5	1.74	0.21
Station 7. Aug. 12, 1941. Lat. 37° 19' N. Long. 62° 48' W. Bottom at 4940 meters.						
2	25.3	36.06	0.24	1.00	3.49	0.07
Grand Mean			0.31	0.62	2.17	0.165

* Ra_U is the radium equivalent of uranium of the preceding column.

the Northwest Atlantic. The radium content of the waters at stations 1, 3, 4, and 5, all in close proximity, are quite similar, both at the surface and at comparable depths, with one exception at 485 meters at station 4; while the radium content of the waters at station 2 and of the surface waters at stations 6 and 7 on opposite edges of the Gulf Stream are different. These features are more discernible in figure 2, which also demonstrates a peculiar feature in that the radium content is at a minimum between the depths of 300 and 700 meters at all stations where subsurface samples were obtained. Surface waters have the highest concentrations and such concentrations are approached but not exceeded by the very deep waters. A similar picture is presented by the data obtained by Pettersson and Rona (1939, Part II) for the Skagerak samples on a shallower depth scale.

Qualitatively, the curves of figure 2 are good mirror images of many depth-salinity curves, as may be noted by reference to *The Oceans* (Sverdrup, Johnson, and Fleming, 1942). The images correspond well in depth, but quantitatively the per-

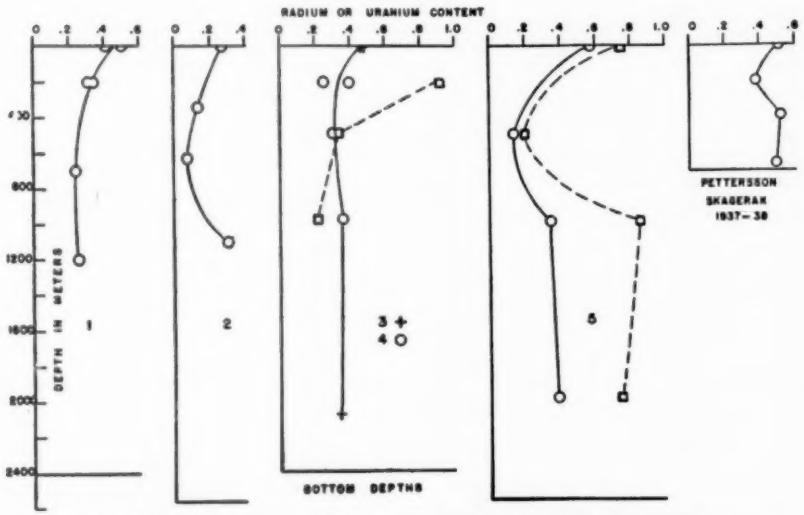

Fig. 2. Variation of the radium and uranium content of ocean water with depth. Circles, crosses, and solid lines are the radium content. Squares and broken lines are the uranium content. Radium content in 10^{-16} g/cc; uranium content in 10^{-9} g/cc. Numbers refer to the station numbers in figure 1.

centage variation in salinity is very much less than the percentage variation in radium content. Consequently, it would appear that the variation of the radium content is not attributable to any physical effect of small salinity changes, but to the presence of different water masses at different depths; that is, different water masses have characteristic radium contents depending upon their origin and past history. Following Helland-Hansen's original suggestion, a water mass is defined by the temperature-salinity curve (*ibid.*, p. 143). Surface data must be omitted because of seasonal and annual variations and local modifications, mainly in the temperature. The stations in table 2 are close to the continental shelf, the Gulf Stream, and the slope waters, and these conditions introduce complications in identifying the water masses from the temperature-salinity data of table 2. In fact, the temperature-depth relations are similar to those existing off the Chesapeake Bay in exhibiting a piling up of water masses against the continental slope (*ibid.*, p. 681, fig. 186).

The plot of radium content against temperature, analogous to the familiar T-S plot of the oceanographer, is shown in figure 3. All subsurface determinations, with no exception, lie on two curves which are similar to the temperature-salinity curves expressing the effect of progressive vertical mixing of three water types (Sverdrup *et al.*, p. 144, fig. 35). The waters having a temperature of about 10° C. and a radium content of 0.33 units in figure 3 are well identified as belonging to the "North Atlantic Central Water." Below about 4°C. the waters having a radium content of between 0.3 and 0.39 units probably can be identified as the "Deep Water" of the North Atlantic when judged by the salinity and temperature. Between these layers there is a mass of water at approximately 300 to 700 meters at stations 2 and 5, beyond the steep portion of the continental slope, characterized by a low radium content of 0.07 to 0.14 units. The source of this water with close to 35.00 o/oo salinity and a temperature of 4.50 to 6.40° C. is difficult to ascertain, but its properties are such that it could have originated in the Labrador Sea and could be connected with the Labrador Current. At station 1 it appears to have diluted the radium content of the deep water by mixing, but it is either absent here as a distinct water mass or was missed in the sampling. This water mass is absent

at station 4 over the foot of the steep portion of the continental slope.

As mentioned previously, surface waters cannot be identified by temperature-salinity relations, but the high-salinity surface waters of the Gulf Stream have significantly lower radium contents (0.24, 0.27, and 0.37 unit) than the low-salinity surface waters to the north (0.46, 0.47, and 0.58 unit).

Neither the present measurements nor the determinations of Pettersson and Rona (Föyn, *et al.*, 1939, Part II) show any marked increase in radium content with depth as reported by Evans, Kip, and Moberg (1938) for the Pacific coastal waters of the United States. These authors considered their results indicative of a continuous process of settling of radium in the sea. While it is true, from observations on the bottom sediments, that radium must be extracted from the water, it is not necessary that this extraction cause any significant change in the radium content at any depth in the ocean, as will be shown in a later publication. It seems more likely that

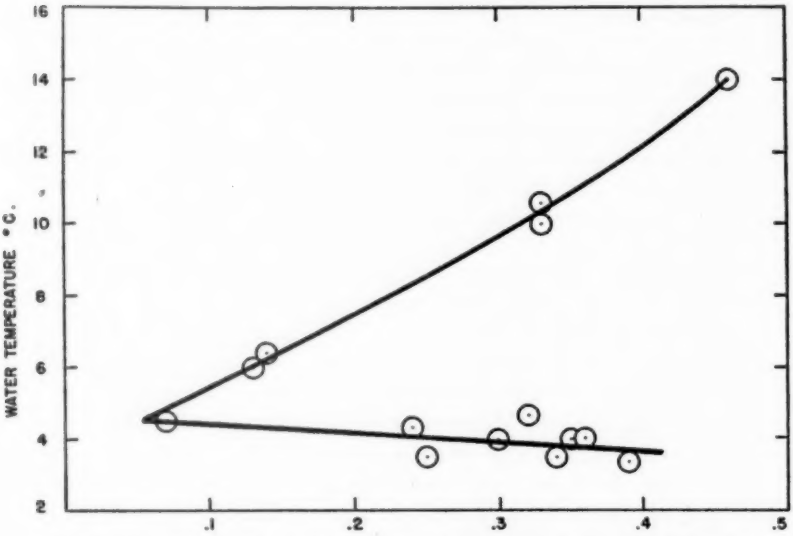

Fig. 3. Diagram showing the radium content-temperature relations analogous to the temperature-salinity relations that delineate different water masses.

the high subsurface radium content found by Evans, Kip, and Moberg is characteristic of a subsurface water mass known to differ from that at the surface along the California coast and indicated in their sampling by higher chlorinities for the deeper specimens. Alternatively, all of their specimens were from inshore waters, at the most 13 miles from land, and such waters usually contain a much higher proportion than the open ocean waters of fine, suspended particles. The radium content of this clay and colloidal material is such that a few tens of milligrams per liter would suffice to provide the difference in radium content between the surface and subsurface inshore waters.

Uranium.—From the data available in table 2, the uranium content appears to vary with depth in the same manner as the radium content, but the results are complete at station 5 only, as seen in figure 2.

The chief importance of the uranium and radium measurements in sea water is illustrated by examining the degree of radioactive equilibrium between the members of the uranium-238 series. The freshly deposited sediment on the deep ocean floor exhibits a peculiar property: the radioelements, uranium, ionium, and radium are not in radioactive equilibrium (Piggot and Urry, 1942*a,b;* Urry, 1942, 1949). Is there a reciprocal relation in the departure from radioactive equilibrium in the water? When two elements in a radioactive series are in equilibrium their activities are equal:

$$N_1 \lambda_1 = N_2 \lambda_2 \quad \text{or} \quad N_1 = N_2 (\lambda_2 / \lambda_1) \qquad (3)$$

where N refers to number of atoms and λ is the disintegration constant. Substituting mass for number of atoms and the values of the disintegration constants, and allowing for 1 part of uranium-235 in 140 parts of uranium:

$$Ra_U = 3.49 \times 10^{-7} U \qquad (4)$$

where the subscript U denotes that the product in the right-hand term is the radium equivalent of the uranium-238. It follows, then, that $Ra/Ra_U = 1$ for equilibrium and that this ratio is a measure of the departure from equilibrium when Ra/Ra_U is not equal to unity.

Table 2 lists the values of Ra_U and the ratios of Ra/Ra_U. Individual values of the ratio of Ra/Ra_U are scattered between 0.07 and 0.28 which indicates that the processes removing radium and uranium from ocean water are to some extent

independent, or that the ratio of Ra/Ra_U in the supply from rivers and eroded shores is variable. The latter possibility is unlikely because the average values of Ra/Ra_U for various water masses, shown in table 5, are practically constant and differ inappreciably from the grand average of 0.165 in table 2, and because the small amount of evidence available indicates in table 4 a constant Ra/Ra_U ratio in river waters.

The waters of the open sea in the North Atlantic, therefore, contain only 16½ per cent of the radium that would be present in radioactive equilibrium with the uranium. This value is in good agreement with the determinations of Pettersson, Rona, and Karlik (Föyn *et al.*, 1939) which average 15 per cent for the Skagerak and Gullmarfjord waters of comparable salinities; that is, greater than 34.5 o/oo. (See table 5.)

From measurements of the radium content as a function of depth in cores of ocean sediments (Piggot and Urry, 1942*b*; Urry and Piggot, 1942; Urry, 1949) one can obtain values for the freshly deposited uppermost sediment of the ratio Ra/Ra_U and of the analogous ratio Ra_{Io}/Ra_U, where Ra_{Io} is the radium equivalent of its parent, ionium (Urry, 1942). A full report on these ratios and their correlation with other properties of the sediments will be published elsewhere. Typical values of Ra/Ra_U and Ra_{Io}/Ra_U can be assigned to the various types of sediments. In table 3 the average values of these ratios are computed for the North Atlantic (figure 253 of *The Oceans*) on the basis of the distribution of the types of sediments now forming in the North Atlantic.

Table 3 shows that in the sediments at the time of deposition there is a large excess of radium over that which would be present in radioactive equilibrium with the uranium. Com-

TABLE 3

Average Value of Ra/Ra_U and Ra_{Io}/Ra_U in the Presently Deposited Sediments of the North Atlantic

Type of Sediment	Area Per Cent	Ra/Ra_U	Ra_{Io}/Ra_U
Terrigenous	10	1.0	1.9
Globigerina	72	5.0	11.0
Red Clay	18	15.0	25.4
Weighted mean	100	6.4	12.7

plete reciprocity in the departure from radioactive equilibrium in the water and the sediment is demonstrated by the value of the product:

$$(Ra/Ra_U)_{Bottom} \times (Ra/Ra_U)_{Water} = 6.4 \times 0.165 = 1.06$$

Ionium.—The concentration of radium in a system which is readjusting to radioactive equilibrium is controlled by the concentration of its immediate parent ionium of medium half-life of 82,000 years, and not by the concentration of the uranium-238 of very long half-life. Consequently, the past history of the ionium content in the bottom deposits can be followed by determining the radium content as a function of depth in a core of ocean sediment; the initial ionium content at the moment of deposition can be determined from such measurements (Urry, 1942). The excess of ionium over equilibrium is roughly twice the excess of radium over equilibrium with respect to uranium, and this factor is reasonably constant for all types of sediments, as noted in table 3, with the exception of the shelf deposits (Urry, 1949).

The reciprocity in the departure from equilibrium in the water and the sediment should hold equally for radium and ionium; hence, according to table 3, the value of $(Ra_{Io}/Ra_U)_{Water}$ should be about $1/12.7 = 0.08$.

It is extremely difficult to measure ionium directly even in high concentrations, and direct measurements in these low concentrations have never been accomplished. An inherent difficulty arises in the universal occurrence of thorium which is isotopic with ionium, but this very property can be used to good effect by employing thorium as a tracer for ionium. In most of the rocks, which are the source of the elements in the ocean, the radioelements are in equilibrium (Urry, 1941); hence $(Ra_{Io}/Ra_U)_{source} = 1$. Th/U ratio in rocks averages 3; therefore, the Th/U ratio in the ocean should be about $3 \times 0.08 = 0.24$, and, from the average uranium content of 0.6×10^{-9} g. per cc. in table 2, the thorium content should be about 1.5×10^{-10} g. per cc. The only reliable measurements on the thorium content of sea water are reported by Föyn and Rona (Föyn *et al.*, 1939 Part III). These workers were unable to detect thorium in sea water but estab-

lished an upper limit of 5×10^{-10} g. Th per cc. This calculation using thorium as a tracer, while crude and neglecting disturbances that may occur between the source and the ocean, substantiates the evidence that there is an efficient process for removing ionium from sea water and depositing it on the bottom.

The ionium content of sea water may be calculated more accurately by introducing the concept of dynamic equilibrium in the ocean, which leads to the following equation:

$$N_{Io}\,\lambda_{Io} + N_{Ra_A} - N_{Ra}\,\lambda_{Ra} - N_{Ra_B} = 0 \qquad (5)$$

where the first term gives the radium produced from ionium in the water, the second term represents the radium added from the run-off from land, the third term, the radium disintegrating in the water, and the fourth term, the radium lost by deposition on the bottom. We consider an area of one $cm.^2$ and a column of water equal to the average depth of the oceans (3.8×10^5 cm.). The radium added to the ocean (0.3×10^{-15} g. $Ra/cm^2/yr$) is obtained from table 4 and McEwen's (1936) estimate of the run-off from land which is equivalent to a depth of 10 cm. of run-off water added per $cm.^2$ of ocean surface per year. The radium lost by deposition on the bottom is found to be 8×10^{-15} g. $Ra/cm^2/yr$, according to considerations to be published in another paper of this series. The uranium and radium content of the ocean water is taken from the averages in table 2. Rearranging equation 5 and substituting masses for number of atoms:

$$W_{Io}(\lambda_{Io}/\lambda_{Ra}) = 0.983 \left[W_{Ra} + (W_{Ra_B} - W_{Ra_A})/\lambda_{Ra}\right] \qquad (6)$$

The left term of equation 6 is the radium equivalent of the ionium in the water Ra_{Io}, and solution of equation 6 gives 0.79×10^{-16} g. Ra_{Io} per cc. The value of $(Ra_{Io}/Ra_U)_{water}$ is, therefore, $0.79/2.17 = 0.36$. The reciprocity in departure from equilibrium in the water and sediment, leading to the value $(Ra_{Io}/Ra_U)_{water} = 0.08$ derived above, fails to hold because a given concentration of ionium in the water is necessary to maintain the content of its daughter element, radium. Nevertheless, the concept of dynamic equilibrium also indicates a deficiency of ionium with respect to equilibrium with uranium, and consequently provides evidence of an efficient process removing ionium from sea water and depositing it on the bottom.

River water.—In applying the principle of dynamic equilibrium familiar to the oceanographers (Sverdrup *et al.*, 1942, p. 160) to study the balance of the radioelements between the water and the sediments, it appears that the radioelements in river water constantly added in solution to the ocean, through erosion of the rocks that constitute the source material, cannot be in radioactive equilibrium. In contrast with ocean water, which is very deficient in radium with respect to equilibrium, the radium content of river water is greatly in excess of the amount required for equilibrium with the uranium content. Earlier results for the radium content of river water are obviously as greatly in error as were the determinations for sea water. A few results were obtained in the course of the present program and are given in table 4. The radium

TABLE 4

The Radium and Uranium Content of River Water

Source of Sample	Ra in 10^{-16} g/cc	U in 10^{-9} g/cc	Ra_U in 10^{-16} g/cc	Ra/Ra_U
Hudson River	0.33	0.022	0.077	4.28
St. Lawrence River	0.25	0.016	0.056	4.46
Mississippi River	——	0.040	0.139	——
Mean	0.29	0.026	0.091	4.37

content is not sensibly different from that of ocean water. The uranium content is much lower, about one twenty-fifth that of the ocean water. The reciprocity of the departure from equilibrium is not complete, however, when judged by these few determinations.

$$(Ra/Ra_U)_{\text{river water}} \times (Ra/Ra_U)_{\text{ocean water}} = 4.37 \times 0.165 = 0.72$$

Comparison with other measurements.—Table 5 summarizes all the recent measurements of the radium and uranium content of sea and river waters. It is difficult to compare the results obtained by the different investigators because the radium and uranium contents are dependent upon depth, salinity, and, possibly, location. The average radium content of the North Atlantic surface waters, reported here, agrees remarkably well with the average of the determinations by Evans, Kip, and Moberg (1938) for the Pacific surface coastal waters of the United States. Measurements of the radium content of the surface waters by Pettersson and Rona

TABLE 5

Summary of Measurements of Radium and Uranium Content of Waters of All Salinities and Localities*

Location and observers	Depth meters	Salinity o/oo	Ra in 10^{-16} g/cc	Ra_U in 10^{-16} g/cc	Ra/Ra_U
North Atlantic					
Rona and Urry	surface	35.63	0.40 (6)	2.6 (3)	0.17 (3)
	200-700	35.07	0.22 (7)	2.1 (3)	0.16 (3)
	900-1200	34.97	0.32 (4)	1.9 (2)	0.17 (1)
	2000	34.86	0.37 (2)	2.0 (2)	0.21 (2)
U. S. Pacific coastal waters					
Evans, Kip, and	surface	33.5-35.0	0.33 (8)	—	—
Moberg	100-900	—	1.0 (4)	—	—
	1300 (bottom)	—	2.9 (1)	—	—
Skagerak					
Pettersson and	surface	32.2	0.51 (2)	1.57 (2)	0.32
Rona, Karlik	200	35.15	0.38 (2)	—	—
	400	35.2	0.52 (3)	4.19 (1)	0.12
	600-700	35.2	0.50 (2)	4.36 (2)	0.11
Gullmarfjord					
Pettersson and	surface	26.3	0.62 (2)	1.26 (1)	0.49
Rona, Karlik	40-100	34.45	0.68 (3)	3.49 (3)	0.20
Baltic Sea					
Pettersson and	surface	7.15	2.0 (2)	0.90 (2)	2.22
Rona, Karlik	80	15.3	1.1 (1)	1.6 (1)	0.69
River water					
Rona and Urry	surface	0.0	0.29 (2)	0.067(2)	4.37 (2)

* Numbers in parentheses indicate the number of samples. The ratio Ra/Ra_U was determined from measurements on the same samples only where the number of such determinations is noted in parentheses.

(Föyn *et al.*, 1939) are not comparable with those of the other investigators because of the low salinity. They are in agreement with the present results in that high radium contents appear to be associated with low salinity in ocean waters. At comparable depth and salinity—namely, between 200 and 700 meters—the average radium contents determined by Pettersson and Rona are about twice those indicated by the present measurements in the North Atlantic; but this is also true of the uranium content, so that the ratios Ra/Ra_U are in very reasonable agreement. This indicates that the differences are probably real and not attributable to variations in experimental procedures or values of the standards upon which the determinations are based.

The available data are inadequate to demonstrate any direct relation between the radium and uranium content of ocean water and the salinity, where only small changes in the salinity are observed. As pointed out, variations in the radium and uranium content in the open ocean appear to be directly related to the typical water masses and only indirectly to the salinity which is a characteristic feature of a typical water mass. When the effect of gross changes in the salinity is studied, however, an important relation between the ratio Ra/Ra_U and the salinity appears to exist. To demonstrate this relation, we make use of the measurements of Pettersson, Rona, and Karlik (Föyn *et al.*, 1939) summarized in table 5. These authors noted a conspicuous increase in the uranium content with increasing salinity but rightly refrained, because of the paucity of data, from drawing any conclusions concerning the radium content and salinity. Values of the ratios Ra/Ra_U, calculated for intermediate salinities from the measurements of Pettersson and Rona, and Karlik, fall on a smooth curve between the end points established by the measurements reported here for zero salinity in river waters and for full ocean salinity. Figure 4 illustrates the progressive changes in the relation between radium and uranium in passing from the fresh waters feeding into the ocean to the open ocean waters. Mixing of the extreme types of water to the extent of about 13 per mille salinity produces concentrations of radium and uranium in radioactive equilibrium; that is, $Ra/Ra_U = 1$, although it cannot be inferred that the uranium-238 series is completely in equilibrium for this salinity be-

cause knowledge concerning the element ionium, between uranium and radium in the series, is lacking.

It is noteworthy that the cycle is completed on passing to the freshly deposited sediment of the ocean floor where the radium is again in excess of the uranium for equilibrium conditions (see table 3).

SUMMARY

New determinations of the radium content of open ocean waters corroborate the very low content measured by previous investigators for samples obtained close to land. Variations of the radium content, both laterally and in depth, appear to be attributable to the presence of separate water masses. The new measurements indicate no increase in radium content or uranium content with increasing depth, but they do demonstrate a minimum radium content, and probably a minimum uranium content, between 300 and 700 meters.

Open ocean waters contain only about 16 per cent of the radium that would be in radioactive equilibrium with the

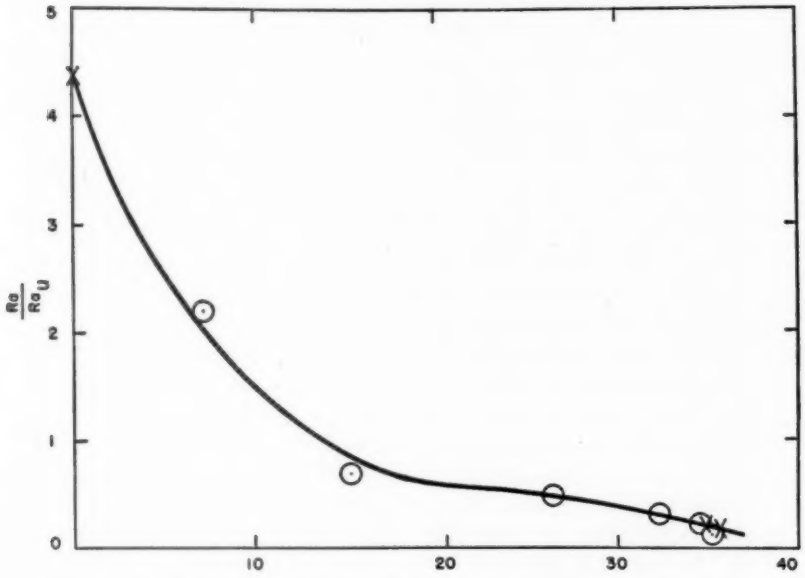

Fig. 4. Variation with salinity of the ratio of radium to the radium equivalent of the uranium in river, inshore, and open ocean waters.

uranium content. Individual values of the ratio of radium to the radium equivalent of the uranium vary within relatively narrow limits for open ocean waters of full salinity. This departure from the equilibrium state is quantitatively the complement of the departure from equilibrium in the freshly deposited bottom sediment, where radium is greatly in excess of the uranium.

There is indirect evidence that the ocean waters also lack the ionium content required for equilibrium and that an efficient mechanism operates to remove ionium from the ocean and deposit it on the bottom.

In river waters the departure from equilibrium is similar to that in the bottom sediments of the ocean.

The ratio of radium to uranium decreases regularly with increasing salinity from zero salinity for river waters to the full salinity of open ocean waters.

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THE CAROLINA BAYS AND A PLEISTOCENE WEATHER MAP

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ABSTRACT. A winter mean pressure pattern for a glacial winter was constructed by assuming a mean 10,000 ft. pressure pattern like the modern one for the month of January, by drawing a temperature pattern parellel to the glacier margin, and by pressure-height extrapolation to sea level. The direction of the surface winds that result from the hypothetical surface pressure pattern coincide with the long axis of the Carolina Bays. The strong pressure gradient on the hypothetical map supports the idea that the orientation of the bays and the Pleistocene loess phenomena are a result of much higher mean winds in glacial times.

INTRODUCTION

THE elliptically shaped depressions that cover the Coastal Plain of eastern Georgia, South Carolina, and North Carolina have been the subject of much discussion and controversy during the last fifty years. These remarkable depressions are all oriented in roughly a northwesterly to southeasterly direction, and from aerial photographs a bay area resembles cookie dough after the cookies have been cut out. Most of these depressions, although once existing as lakes, are now filled with peat and support a thick swamp vegetation containing among other plants bay trees (*Persea*), from which these areas get their name. An aerial photograph of some bays is shown in plate 1.

The extensive discussions and observations regarding the origin of these structures are summarized by Johnson (1942). His book presents the theory that the depressions were formed by the combined action of ground water flow, artesian waters, solution, and the action of winds. Johnson also summarizes and discusses the rival theory of the origin due to a shower of meteorites as presented by Melton and Schriever (1933), Prouty (1935), and others. There is still no agreement as to the initial formation.

Including the theory of Grant (1945) that the bays were fish-spawning depressions, a review of the discussions indicates that regardless of the proposed cause of the original depression, the action of wind is considered by nearly all authors to be a factor in at least rounding the edges of these sand-bordered "saucers" or determining orientation. Cooke's (1945) complex idea of the details of the vortex-producing action of

the wind is probably incorrect in view of the observations in figure 3 and criticisms by Grant (1945).

The recent work on pollen stratigraphy and morphometry by Frey (1949, 1950, 1951) and Buell (1939, 1946) and the radioactive carbon dating by Arnold and Libby (1951) have indicated that the depressions are at least older than the last Pleistocene glaciation. The presence of endemic fish and mollusks also indicates their age (Hubbs and Raney, 1946). The stratum of blue-gray mud that is found in all the bays has been postulated to be loess (Deevey, personal communication, and Frey, 1951). The wind-oriented lakes in Alaska recently reported by Black and Barksdale (1949) have been compared to the bays. In the case of the Alaskan lakes the orientation is with the strongest winds which at times blow 100 miles per hour. South African pans have also been compared favorably (Shand, 1946).

If, as many authors think, the orientation as well as the rounded edges is due to prevailing wind direction, the bays represent a wind direction observation from the Pleistocene. With this observation it is possible to limit the possible patterns of wind flow and temperature distribution in the Pleistocene. The purpose of this communication is to construct a reasonable winter Pleistocene mean surface weather map for the eastern United States. If the wind flow across the Carolinas is compatible with the bay orientations the map may be considered to have some validity. Or if the temperature and upper air pressure assumptions seem reasonable for the Pleistocene, the role of the wind in determining the bays may be supported.

While the author was assisting David G. Frey on an investigation of some of these lakes in 1948, he had an opportunity to observe wave patterns under approximately 35 mph wind. The pattern of waves was as one should have expected for a shallow depression. The action of wind waves in lakes to reduce surface area has long been known (Johnson, 1919). The wave fronts, of course, turned parallel to shore as they approached, as in figure 3. The diverging wave fronts were undoubtedly associated with some underwater convergence and return flow due to some mass transport of the surface waters. The oval shape of the depressions is a sort of resultant wind rose summing the stresses.

The present strongest winds usually occur during strong

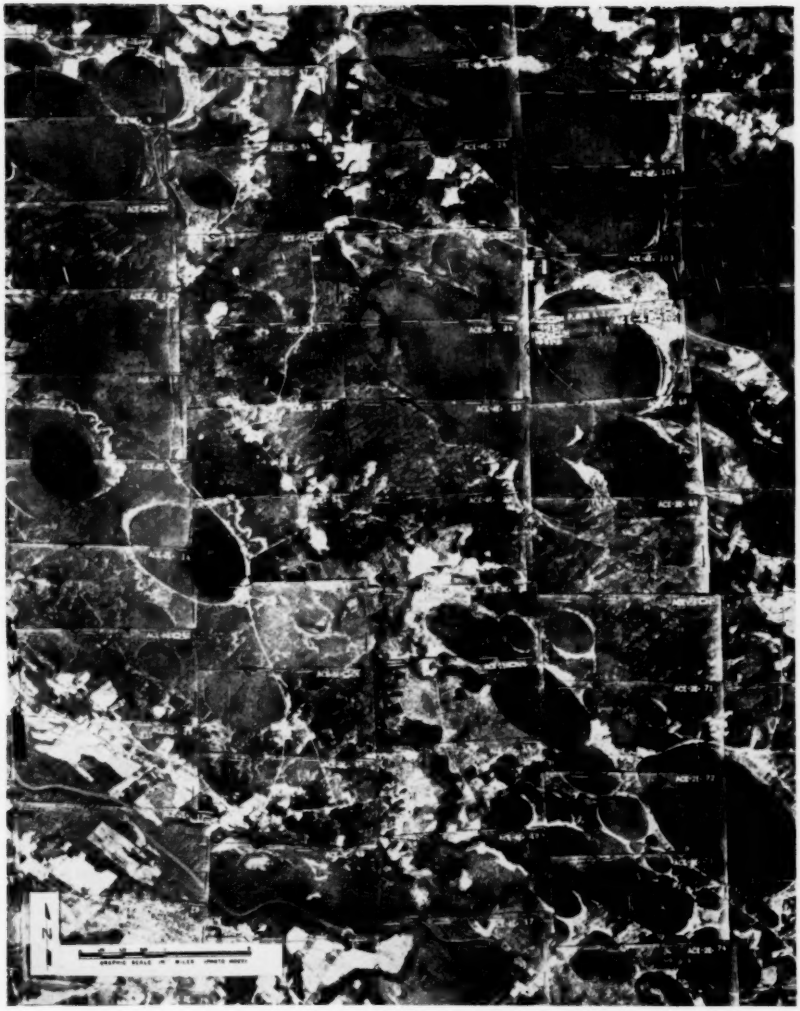

Plate 1. Composite aerial photograph of Bladen County, North Carolina, showing oriented Carolina bays. Photo courtesy of U. S. Dept. of Agriculture.

cold front passages from the northwest, but even under these conditions sustained winds rarely exceed 50 miles per hour. Although sufficient to keep the oval shapes somewhat oval in those bays still containing lakes, the winds do not seem capable of radically changing the initially different shape of a lake. However, it is very possible that during the Pleistocene, the winds were of a considerably greater order of magnitude. The phenomenon of Pleistocene loess has usually been attributed to bare exposures making possible more collection by the winds (Flint, 1947). However, the possibility of much stronger winds capable of bearing more matter is also very reasonable, as will be shown.

These ideas about the role of wind in the Pleistocene are qualitative and not at all new (Hobbs, 1926). Buell, for example, has compared Greenland winds to possible Pleistocene flow over the Bay Lakes (personal communication). However, by constructing a weather map, these old postulates are shown to be harmoniously related quantitatively by hydrostatic and geostrophic functions.

ASSUMPTIONS IN CONSTRUCTION OF THE PLEISTOCENE MAP

The basis for construction of the Pleistocene map is an assumed 10,000 ft. pressure field superimposed on an assumed mean temperature distribution for the layer of air between the surface and 10,000 ft. levels. The surface pressures are thus determined according to the familiar hydrostatic relationships. In practice the calculations were made with a Bellamy pressure height slide rule.

The temperature field was constructed by drawing two boundary mean isotherms and filling in the space between them with approximately equally spaced isotherms. The northern isotherm was drawn along the southern border of the Wisconsin Glaciation as taken from Flint (1947). Keeping in mind that air masses over snow and ice cover in source regions tend to have an isothermal or more stable lapse rate in the lower layers, the mean temperature was assumed to be similar to the surface temperature in the winter time around ice sheets in northern regions. Fortunately the thickness of ice can be neglected if an isothermal lapse rate exists. Thus a —20° C. isotherm seems reasonable. Greenland has a similar temperature distribution today. Over a snow cover the radiational

heating from the ground is not great. Actually such temperatures occur at the same latitude today during cP outbreaks. Thus it is not unreasonable to expect —20° C. mean temperatures at lower latitudes in the layer over an ice sheet.

The southern boundary isotherm of +15° C. was determined by assuming that the land and sea surfaces in the areas south of Florida had similar temperatures then as now. It is probable that these areas which include Gulf Stream source were not much colder than at present since most of the modern theories of glaciation postulate only small if any change in equatorial temperatures. Thus, using the present sea surface temperatures and assuming a moist adiabatic lapse rate for

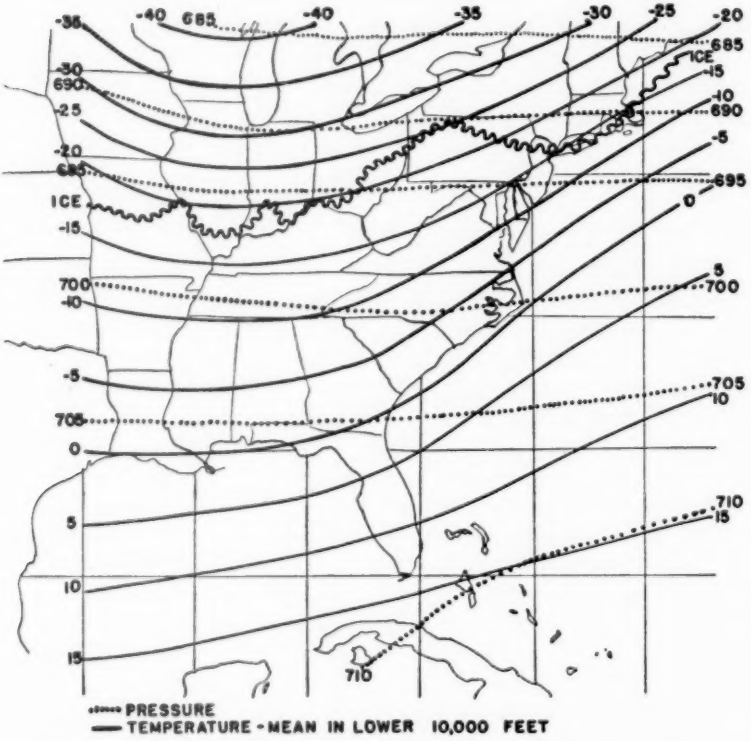

Fig. 1. Data used to construct Pleistocene surface pressure map. Pressures are the mean 10,000 ft. pressures for January from U. S. Weather Bureau Normal Monthly Pressure charts. Isotherms are drawn according to assumptions in the text.

maritime tropical air masses, a mean temperature isotherm of 15 degrees is drawn south of Florida. The isotherms drawn between the boundary isotherm were drawn so as to resemble present day patterns especially in paralleling the coast line and Gulf Stream position. Although approximate, these assumptions have the merit of objectivity and simplicity as a first approximation. The resulting temperature patterns are shown in figure 1. The surface temperatures would vary somewhat because of the steeper lapse rates expected in polar air moving southward over land which is warmer than the air in contrast to the more stable lapse rates over the ice and over the ocean.

The pressure pattern at 10,000 ft. was assumed to be the same as the present mean 10,000 ft. pattern of pressure for January. This is of course most certainly not exactly true since the whole world circulation is interconnected and changes as a whole when a part changes. However, it is to be expected that if the general features of the world circulation are unchanged, the presence of a dense cold layer of air due to cooling over a glacier will affect the weight of the air above 10,000 ft. far less than it does the surface pressure. To be sure, there will probably be some lowering of the tropopause and pressures aloft, but by and large the effect of the dense air in the lower layers will be to increase the surface pressures far more than to change the upper air. This is reasonable since this is the behavior of air masses over Greenland, over Canada and Siberia in winter. The presence of a cold dense air mass in a fairly low latitude so as to be under the weight of relatively high 10,000 ft. pressures associated with the horse latitudes will tend to create a much higher pressure over North America than exists today. The use of the 10,000 ft. pressures as they are today in winter is probably the best approximation that can be made at present without being arbitrary. The map that will be constructed thus becomes the map that will exist if a cold permanent air mass were inserted in North America under the present overall general circulation.

Although the map being constructed is a mean map for a Pleistocene winter, the existence of the ice sheet will tend to reduce the variability by eliminating many of the frontal systems. This is what has been observed to happen on a small scale in Greenland. There is a correlation between the amount

of ice in the Greenland sea and the frontal systems that reach this far north (Schell, 1940). Similarly the pressure patterns in the winter over Siberia, Antarctica, and Greenland tend to be less variable. If this point is correct, the mean map for the Pleistocene should actually represent the flow on a good number of days.

THE MAP

Figure 2 is the result of the pressure height calculations based on the mean temperature and 10,000 ft. pressure fields in figure 1. Superficially it resembles eastern Asia in the wintertime. The pressures are quite high and the pressure gradients very strong. Again this pattern resembles that of Greenland and Antarctica where glaciers are in close juxtaposition to the sea. In general the eastern United States was probably

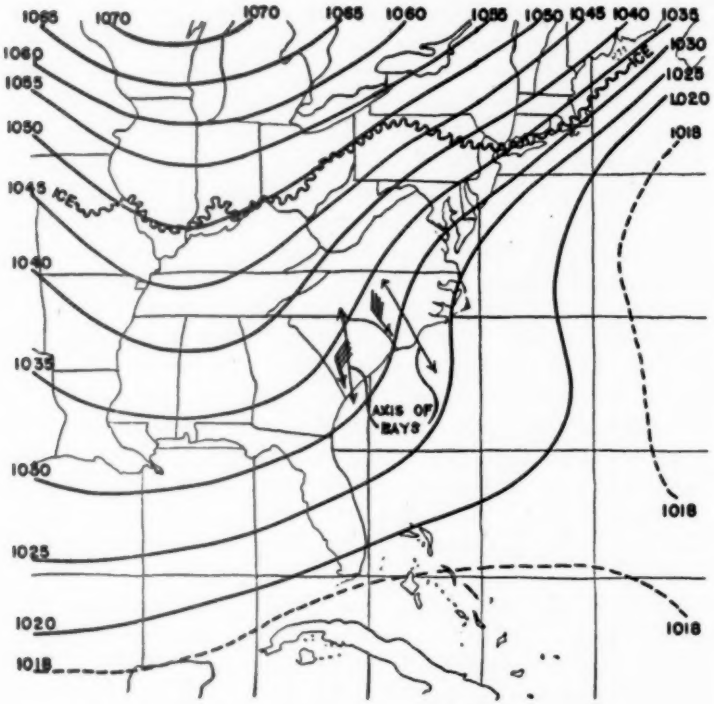

Fig. 2. Pleistocene mean sea level pressures in winter.

dominated by anticyclonic conditions and a frontogenetic trough off the coast.

These interpretations do not contradict most of the interpretations of Pleistocene climate as summarized in Brooks (1949), but they provide an objective synoptic picture to supplement the climatic indications which are more a function of precipitation and temperature means.

If the Pleistocene map is somewhat near the correct answer, many deductions can be made about Pleistocene climate. Steep lapse rates, turbulent lower layers, low relative humidities, and unstable type clouds in the lower layer must have been characteristic of much of the continent. Precipitation was possibly less, mostly of frontal type due to overrunning from cyclones off the coast, except south of the polar trough over Puerto Rico. With high winds, the possibility of spruce pollen being blown great distances suggests caution in the interpretation of conifer distribution from pollen analyses.

In figure 2 the winds that result from the calculated pressure pattern are drawn across the isobars at an angle of about 40 degrees. Although winds above 2000 ft. blow along the isobars, the friction at the surface causes the winds to blow across the isobars toward low pressure at an angle (Byers, 1944). Thus the surface wind direction seems to correspond roughly with the axes of the Carolina Bays. The frictional action also decreases the surface wind velocity below that which would result in free air from the map's strong pressure gradient and anticyclonic curvature.

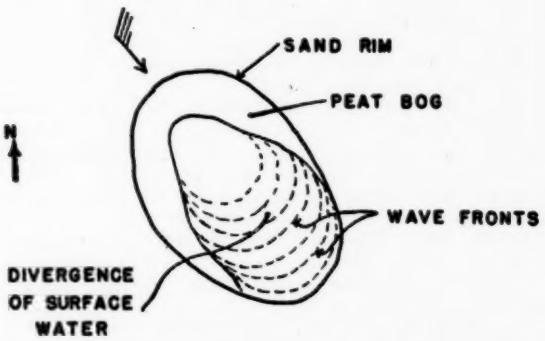

Fig. 3. Waves on Singletary Lake, North Carolina.

ACKNOWLEDGMENTS

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THERMAL DISINTEGRATION OF SEDIMENTARY ROCK

D. G. MacVICAR, JR.

ABSTRACT. Heat treatment of highly indurated rocks separates fossils from the matrix and loosens the detrital grains from the cement. Temperature is raised above either a mineral inversion point or a transformation point and held there long enough for change to occur throughout the rock. Differential expansion at the border between different substances or diversely oriented crystals causes separation into the component parts. Application of the technique to one limestone gave separation of delicate trilobite carapaces that were as acid soluble as the limestone and also disclosed abundant ostracods; tried on a Precambrian limestone it disclosed pore cells of Porifera and even one small sponge. The sandstone immediately below the Holyoke basalt had been refractory to all other treatments but came apart easily by this one, to facilitate study of roundness of grains and grain sorting in the sediment.

HISTORY OF STUDY

DEVELOPMENT of the heat treatment procedure arose from need to remove from a highly indurated acid soluble limestone matrix the equally acid soluble trilobite carapaces. This was worked out in order that another student might continue his study of a Paleozoic faunule. Heating to raise the pressure of CO_2 above that of the atmosphere decomposed the firm calcium carbonate to powdery calcium oxide, from which the hard slightly phosphatic fossils could be separated easily. Further applications of the heat treatment were suggested by a consideration of the principles involved or only slight extensions of the idea. Slight chemical variation between a fossil and its matrix led to unequal friability, and the greater departure of siliceous fossils under treatment made their removal much easier. Study of causes for fracturing in certain treated fossil specimens showed that differential thermal expansion of different minerals could be used advantageously in the disintegration of highly indurated sandstones.

TECHNIQUE

All specimens were treated in an electric furnace, following a set procedure. Upon removal, the fossil products from limestone had to be kept in a desiccator to prevent hydration and destructive expansion. The major problems were first

to heat the material to its critical temperature, and second to heat it slowly so that heat variation, adequate to cause exfoliation, would be minimized throughout the rock. Heating just over 100° C. for an hour expelled occluded water. After this preliminary heating, the specimens were placed in the furnace and raised to 1000° C., using the normal furnace temperature gradient.[1] This temperature was held for one to three hours, depending on the size of rocks, to insure total conversion. Then the furnace was turned off and allowed to cool slowly to room temperature. The furnace door was kept closed until the entire furnace had cooled to near room temperature to prevent too-rapid cooling and rupture of fossils or detrital grains. After removal, the fossiliferous specimens were placed in a desiccator. This was essential, since the lime matrix was so hygroscopic that the rock would crumble to pieces within 48 hours under normal atmospheric conditions.

REMOVAL OF FOSSILS

Extraction of the fossils from their matrix required not only these composition differences, involving separate heat transformation, but also care in manipulation during actual removal of the fossil. Fossils to be separable must contain at least significant traces of either phosphate or silica and be cemented by a calcareous matrix.

Heat treatment softened the matrix to powdery calcium oxide while the fossils remained relatively hard. Formation of calcium oxide began once the carbon dioxide pressure from the mineral exceeded the critical partial pressure of atmospheric carbon dioxide. The rate of this transformation may be interpreted from the graph (fig. 1.). Within the temperature range suggested, fossils containing tricalcium phosphate or silica remained intact. Those possessing hydrous silica lost their water. The lime from calcite grains, penetrating a phosphatic or siliceous fossil, was supported by the inert phosphatic framework and the matrix material could be separated.

A variety of techniques were employed in actual removal of the fossil from its cement. Usually, the calcium oxide could be scratched loose with a fine needle and brushed away; any area that was particularly refractory was softened up by local

[1] Approximately 4°C. per minute.

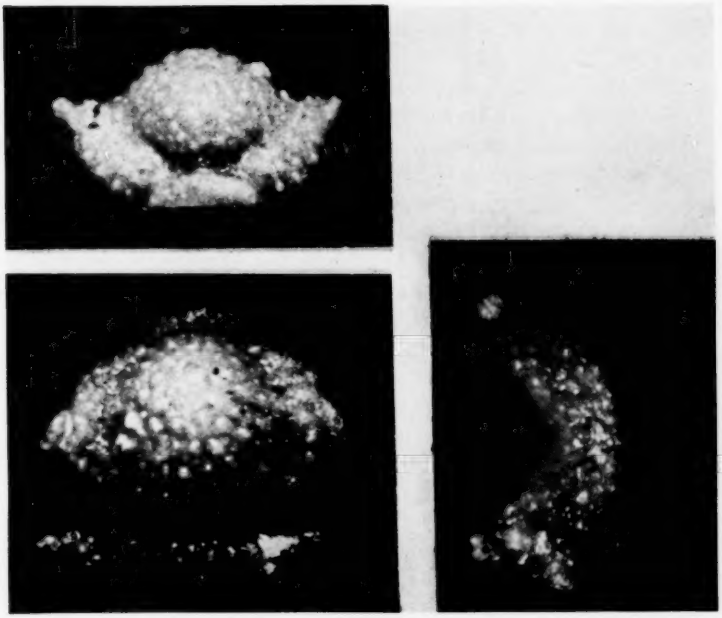

Plate 1. Cranidium of the trilobite *Dimeropygiella* n. sp.
The photographs show the detail of the pustulose exterior as seen from the front, top, and side. The glossy surface is due to partial thermal reorganization of the tricalcium phosphate.

hydration by water applied through a glass tube drawn to a thin capillary. Too much water caused sudden and local expansion of the matrix with resulting disintegration of the fossil. Coating the fossil with a thin film of shellac as it was exposed prevented disruption along fractures.

SEDIMENTARY ROCK DISINTEGRATION

Disintegration of highly indurated, noncalcareous, detrital sedimentary rocks has long been a problem to the stratigrapher. Heat treatment of these rocks caused excellent granular separation as a result of thermal expansion differences and mineral inversion. Major zones of strain were created at the borders of adjacent different minerals, due to their widely varying thermal expansion and thermal anisotropism. In the particular case of quartz, inversion from the alpha to the beta variety may have been a major factor in granulation. Strains were adequate to permit most specimens of arkose and graywacke to be crushed between the fingers although some required pressure of a wood block.

The actual mineral recovery was excellent; some large pebbles were extracted unbroken and many heavy mineral grains were removed intact. Euhedral zircon was retrieved from one sandstone; mica and microcline grains with rounded

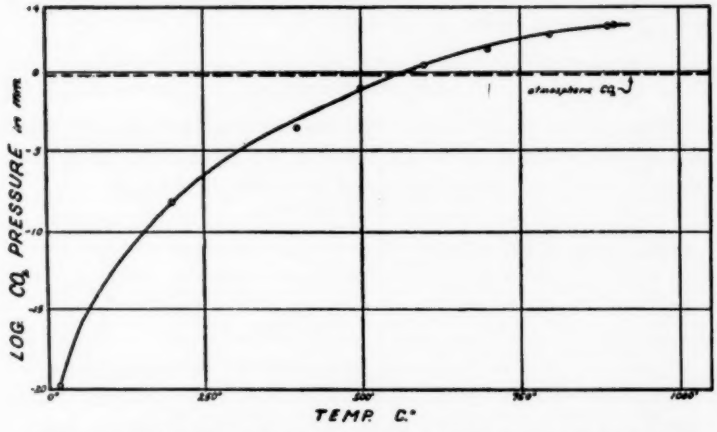

Fig. 1. Graph showing CO_2 pressure of $CaCO_3$ plotted relative to C°. The CO_2 pressure of $CaCO_3$ above 575°C exceeds the CO_2 pressure in the atmosphere and $CaCO_3$ begins to break down to the component oxides. Rate of decomposition becomes significant above 750°C.

edges were extracted from an arkose. Pebbles composed of a variety of minerals usually disintegrated and were lost, and this is a defect inherent in the process. Quenching generated excessive strain within a particular mineral grain and caused both exfoliation on grains and fractures that passed through the grains rather than around them.

SOME APPLICATIONS

Tubular structures with pores were separated from the Precambrian limestone of the Serie des Mines in the Belgian Congo. These seem to be the pore cells of sponges. One good sponge was worked almost free from this rock early in the study but it was broken and crumbled before the use of shellac was appreciated. In all probability, other phosphatic or siliceous Precambrian microfossils in limestone can be disclosed by means of this heat treatment. Since the method will separate undetected slightly phosphatic or siliceous fossils from a highly crystalline limestone, the paleontologist may find it applicable to recovery of a microfauna.

The method serves also to break sedimentary rocks down to sediment for mechanical analysis. Thus highly indurated sandstone, arkosic conglomerate, or graywacke, are prepared by this treatment for exactly that same sort of study to which ordinary sediment is subject.

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MIDDLE CAMBRIAN OF THE ATLANTIC REALM IN EASTERN GASPÉ *

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ABSTRACT. A new species of trilobite from eastern Gaspé is described as *Centropleura belli*. The occurrence of a *Centropleura* shows that a seaway carrying a late Middle Cambrian fauna of Atlantic affinities occupied the area, and indicates that a mingling of Atlantic and Pacific type faunas may have occurred in the St. Lawrence seaway during the Middle Cambrian.

INTRODUCTION

THE trilobite described in this paper was found during a restudy of the older palaeontological collections of the Geological Survey of Canada. It was collected by Robert Bell on a tributary of the Dartmouth River in the eastern part of the Gaspé peninsula, Quebec, in 1862. Fortunately, Bell's field notes are available, and it has proved possible to locate the fossiliferous outcrop accurately. The fossil is described as a new species of the genus *Centropleura* Angelin, a genus characteristic of the late Middle Cambrian faunas of the Atlantic realm. The significance of the occurrence of a member of this genus in the interior of the continent, and its bearing on our knowledge of the Cambrian history of the area, are discussed.

The author wishes to thank Professor B. F. Howell, of Princeton University, for discussing with him some of the problems mentioned here and for drawing his attention to Logan's reference to this fossil.

LOCALITY

The trilobite was collected on July 3, 1862, on a cross country traverse which began at Bell's base camp, located on the main Dartmouth River just west of the mouth of Ruisseau Jean Louis, and proceeded N. 45°E across Ruisseau Jean Louis into the region between that stream and Trout River. About 4¼ miles from the starting point, the traverse crossed a small brook flowing southeastward (presumably into Trout River). The specimen was collected from a shale bed out-

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cropping in the bed of this brook. The locality lies in the north-central part of Blanchet county.

AGE

The trilobite described here is certainly referable to the genus *Centropleura* Angelin, 1854. Howell (1933) recently discussed this genus, and restricted it to the forms having unevenly curved palpebral lobes which do not reach back to the posterior corners of the cranidium. Westergard (1949) also discussed the classification of the genus, and retained Howell's subdivision of it with some question. The Gaspé specimen clearly belongs to *Centropleura* as restricted by Howell, and is described as *Centropleura belli* sp. nov.

The genus *Centropleura* as thus restricted is known only from late Middle Cambrian rocks. The genotype, *C. loveni* (Angelin) occurs in the Andrarum limestone of Sweden, and the other two Swedish species, *C. angelini* Westergard and *C. angustata* Westergard occur at the same horizon. These species are all, therefore, referable to the *Paradoxides forchhammeri* stage of Westergard's latest zonation of the Swedish Cambrian (1946). Westergard (1949) with some doubt refers the form from Bennett Island, north of Siberia, to *C. angelini*, and Lermontova (1940) has described a new species, *C. siberica*, from the *forchhammeri* beds of the Anabar region, Siberia. The only previously described American species, *C. vermontensis* Howell, is believed to be of about the same age (Howell, 1937). It seems safe, therefore, to regard the Gaspé species as being of late Middle Cambrian age.

GEOLOGICAL SETTING

The trilobite here described was mentioned by Logan (1863, p. 882). He referred to it as "an imperfect trilobite, very much resembling *Paradoxides harlani*," but later said "the imperfection of the specimen, however, is such that it may possibly be a *Dalmanites* instead of a *Paradoxides*." His doubt as to the identity of the specimen prevented later workers from accepting this occurrence as a proven locality for Middle Cambrian rocks. Logan referred the rocks of the area to his Quebec group, and later workers have retained this classification, and have generally referred them to the Lower Ordovician.

Rasetti (1948) recently discussed the Cambrian and Early Ordovician stratigraphy of the St. Lawrence valley, and showed that a part of the old "Quebec group" was of Lower Cambrian age. However, he concluded that most of the rocks mapped by earlier workers as "Quebec group" or "Sillery formation" to the east of Quebec City should probably be referred to the Lower Ordovician Lauzon formation. Middle Cambrian trilobites have long been known to occur in boulders in limestone conglomerates within this formation. Rasetti (1948) recently described and figured these trilobites. Until recently, the Middle Cambrian limestone from which these boulders must have been derived had not been known to outcrop, however, Laverdière (1949) has now described an occurrence of bedded Middle Cambrian limestones among Ordovician rocks near Quebec, but is undecided as to whether these rocks are faulted up from beneath, or whether they represent an unusually large block in the Beekmantown conglomerates.

Howell (1937) described a large fauna of late Middle Cambrian age from the St. Albans shale, of northwestern Vermont. This fauna includes a *Centropleura*, closely related to the Gaspé species. This Vermont occurrence represents the nearest proven occurrence of Middle Cambrian rocks to the Gaspé locality. Since the fossil from the Gaspé was found in an outcrop of shale, rather than a limestone boulder, it seems reasonable to conclude that it represents a true occurrence of Middle Cambrian rocks, rather than another locality for Middle Cambrian boulders in later conglomerates. The rocks in which it was found are probably of the same age as the St. Albans shale of Vermont.

PALAEOGEOGRAPHICAL IMPLICATIONS

Students of Cambrian rocks have long recognized that the Cambrian faunas fall into two distinct divisions, which have almost no species and few genera of fossils in common. One of these groups of faunas occurs in the Cambrian rocks in the area about the North Atlantic Ocean, the other in the interior of North America and about the Pacific Ocean. In North America, the Atlantic realm faunas are confined, with very few exceptions, to the areas which lay within the early Palaeozoic Acadian geosyncline, that is, to eastern Newfoundland, Cape Breton Island, New Brunswick and eastern Massa-

chusetts. It has been postulated that a land barrier, the so-called New Brunswick geanticline, lay along the northwest margin of the Acadian geosyncline and prevented the mingling of the faunas of the two separate realms.

Centropleura is a genus which usually is confined to rocks of the Atlantic area; however, Howell (1937) has shown that it occurs along with other Atlantic realm genera in Vermont. A seaway carrying an Atlantic fauna must, therefore, have extended into Vermont during late Middle Cambrian time, presumably through some break in the land barrier. The Gaspé occurrence now indicates that this seaway must also have covered the Eastern Gaspé area. Rasetti has shown conclusively (1946) that Middle Cambrian rocks are lacking in the area about Quebec City; hence this seaway probably did not extend far up the St. Lawrence valley.

The Middle Cambrian faunas from the Ordovician conglomerates described by Rasetti (1948) are believed to be somewhat older than the *Centropleura* fauna, and those described by Laverdière (1949) are certainly older, being referred to the zone of *Paradoxides hicksi*. Both these faunas suggest a mingling of Atlantic and Pacific realm genera, as the agnostean trilobites in both cases are referable to genera well known from Europe, whereas the non-agnostean trilobites belong to genera characteristic of the Pacific realm. It seems certain, therefore, that the St. Lawrence area during Middle Cambrian time was covered by seaways with both eastern and western faunas, which mingled to some extent.

PALAEONTOLOGICAL DESCRIPTION

Family Paradoxididae Emmrich, 1839.

Subfamily Centropleurinae Howell, 1933.

Genus *Centropleura* Angelin, 1854.

Centropleura belli sp. nov.

Plate 1

1863. cf. *Paradoxides harlani* Green; Logan, Geology of Canada, p. 882.

Material.—The holotype and only known specimen consists of the cranidium and ten thoracic segments. It is No. 10121 of the type collection of the Geological Survey of

Canada, and was collected by R. Bell in 1862 from the Dartmouth River, Gaspé, Quebec.

Dimensions.—Length of cranidium and ten thoracic segments, 72.6 mm., length of cranidium, 33.4 mm.; length of glabella, 31.0 mm.; maximum width of glabella, 23.8 mm., width of glabella at occipital furrow, 17.2 mm.; width of fixed cheek at posterior glabellar furrow, 10.4 mm.; length of eyelobe, 16.2 mm.

Description.—Cranidium broader than long, gently convex, rounded in front. Glabella prominent, expanding anteriorly, reaching marginal furrow, widest opposite second glabellar furrow, bordered by deep, narrow, dorsal furrow. Four pairs of glabellar furrows visible, the anterior pair run from dorsal furrow in front of the palpebral lobe obliquely inward and backward; the second pair do not join the dorsal furrow, but begin just inside that furrow, extend directly inward, and are joined across the axis of the glabella; the third pair extend from the dorsal furrow directly inward, and are also impressed across the axis; the posterior pair are broader and shallower than the second and third pair, and are impressed all the way across the glabella. The occipital furrow is broad and shallow, and curves forward where it crosses the axis of the glabella. The second and third furrows are very close together, the third and fourth are more widely separated and the distance between the fourth glabellar and occipital furrows is very broad. The glabella reaches the marginal furrow in front, thus no brim is present; the border is narrow and flat in front of the glabella, but widens somewhat laterally, where it is crossed obliquely by the broad, shallow marginal furrow.

The eyelobe is long, running from the dorsal furrow between the first and second glabellar furrows outward and backward, curving backward and finally inward, ending opposite occipital furrow. Fixed cheek thus narrowing to a point in front, widening backward, gently convex. Posterior limb narrow, extending laterally just beyond end of eyelobe. The facial suture thus extends backward around the border, thence inward and forward around the back of the border to the dorsal furrow; thence turning sharply backward to curve around the eyelobe, finally outward and backward to the posterior border.

The specimen shows ten thoracic segments. The axis is broad and well defined, the pleura are obliquely grooved, and are strongly turned down at a point removed from the dorsal furrow by about two-thirds the width of the axis, so that they appear to end bluntly; close inspection shows, however, that the points are buried in the matrix and are not visible. The pygidium and free cheek are not known.

Comparisons.—*Centropleura belli* is immediately distinguished from all other described species of *Centropleura* except *C. vermontensis* by the joining of the second and third pairs of furrows across the axis of the glabella. In the European and Asiatic species these furrows do not extend entirely across the glabella. Howell (1933) showed that in *C. vermontensis*, these furrows do not cross the glabella in the smaller specimens, but do so in the larger forms. He, therefore, suggested that *C. vermontensis* was likely derived from, and somewhat younger than, one of the European species in which these furrows are not continuous in the adult form. *C. belli* is probably closely related to *C. vermontensis*, from which it differs chiefly in the irregular spacing of the glabellar furrows, and also in having a more evenly expanding glabella.

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Plate 1. *Centropleura belli* sp. nov., holotype, G.S.C. No. 10121, natural size.

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ON THE ASSOCIATION OF PERTHITIC MICROCLINE WITH HIGHLY UNDULANT OR GRANULAR QUARTZ IN SOME CALCALKALINE GRANITES

FELIX CHAYES

ABSTRACT. Microperthite is on the whole uncommon in the micaceous calcalkaline granites of New England, Texas, and the southeastern states. It is usually rare or lacking if quartz is ungranulated and shows only moderate undulance, may or may not be common if quartz extinction is highly undulant, and is never rare if quartz is extensively granulated. The shearing stresses which render quartz extinction undulant and finally granulate the quartz evidently induce or accelerate the unmixing of albite-poor microcline which might otherwise remain indefinitely metastable. Alternatively, if the albite is already submicroscopically exsolved, as often seems to be the case, stress promotes its recrystallization into units of optically resolvable dimensions.

ALTHOUGH microscopically resolvable perthite of one kind or other is usually mentioned as a major constituent in most descriptions of granite, my experience indicates that in micaceous calcalkaline granites it is frequently lacking and rarely abundant. There is excellent reason for supposing that in general the potash-feldspars of such rocks should not be soda-free. Available chemical analyses of them almost invariably show appreciable amounts of soda, though in many cases the purity of the samples is suspect. Experimental work on the subject (Schairer, 1950; Bowen and Tuttle, 1950) implies that if soda is present in the medium from which a potash-feldspar is forming, some of it will almost certainly get into the potash-feldspar. Both alkalis being abundant in calcalkaline granites, it would appear that almost regardless of their genesis, the potash-feldspar of such granites should contain some soda.

The amount of soda so dissolved is probably small, but we may not assume that it is negligible. In a slowly cooled magmatic granite, or a granite of whatever origin subjected to mild thermal metamorphism, this dissolved albite ought to exsolve from its host. Depending on the amount of albite it once contained, the dominant alkali-feldspar of calcalkaline granite should then be either microcline microperthite or at least a perceptibly perthitic microcline.

In fact microcline in the calcalkaline granites of New England, Texas, and the southeast commonly contains only negli-

gible traces of perthitic intergrowth. One can carefully search entire thin sections of many of these granites without coming on a grain of it. The amount of perthitic albite is rarely sufficient to permit its useful separation from the remaining plagioclase in modal analysis. Why the microcline of calcalkaline granites commonly is not visibly perthitic I do not know, but I have recently found some clue to circumstances under which it may become so. The work is part of a general petrographic study of calcalkaline granites and is extracted from the full report because of the present intense interest in feldspar.

In brief, there seems to be a strong association between the frequency of occurrence of perthitic intergrowth in microcline and deformation, as evidenced by undulation and granulation of quartz. The observations which first suggested this relation are recounted in the two succeeding sections, and in the third the results are extended to certain other granites.

PERTHITE AND QUARTZ DEFORMATION

Salisbury, North Carolina, granite.—Salisbury is a coarse, moderately gneissic granite in which quartz is always either magnificently undulant or entirely granulated. In specimens of the first type large grains and patches of undulant quartz are usually mantled by narrow films of granulated quartz, and from these mantles granulation occasionally spreads inward along cracks. Feldspar may be shattered or faulted, and microfaults in it are sometimes filled by wedges of quartz, but it is rarely if ever granulated.

In the other common variety of Salisbury granulation of quartz is complete, undulation is absent, and the original patches of coarse quartz, now fine-grained aggregates, tend to elongate and spread through the rock. Feldspar is also granulated but the effect is less striking because the new grains, which are often bounded on two or three sides by cleavages and hence may appear subhedral,[1] are commonly rotated and separated from each other by irregular tendrils of the much more finely granulated quartz.

Differences between the undulant and granulated facies are conspicuous under very low magnification, particularly under crossed nicols. Because of the generally coarse grain

[1] Or porphyroblastic!

of the rock they are much less prominent with high magnification. What is more surprising, however, is that they are practically imperceptible in the hand specimen. To the unaided eye, or even with a hand lens, both facies are coarse, moderately gneissic granites, and it is only after considerable practice that one learns to discriminate between them by the slightly smaller apparent grain size and very slightly more pronounced gneissic fabric of the crushed variety.

In most of the specimens granulation is either complete, so that no large undulant grains remain, or it has barely begun, and the slender mantles of granular quartz which surround the large undulant grains rarely extend into the interiors of these grains or outward from their margins. In only three of the twenty-one specimens collected are both undulant and granulated quartz abundant.

Perthitic microcline occurs in all parts of the Salisbury mass, and its association with quartz of the two types is highly suggestive. It may be either conspicuous—*e.g.*, present in at least a third of the microcline grains—or very rare in the undulant facies, but it is always conspicuous when quartz granulation is complete. Paired slides from each of the twenty-one specimens were carefully studied under low magnification and classified as shown in table 1. (Results for slides from the same specimen were identical.)

TABLE 1

Perthite Frequency and Quartz Deformation in Twenty-one Specimens of the Salisbury Granite

Quartz	*Perthite*		
	Abundant	*Intermediate*	*Rare*
Dominantly undulant	5	2	4
Both types conspicuous	0	0	3
Completely granulated	6	1	0

There are several ways in which the intermediate groups can be combined with the extremes; with differing emphasis all lead to the same conclusion, *e.g.*, that perthite may be common or rare where quartz is undulant but is never rare where quartz is completely granulated. That undulance *per se* is not critical is best shown by the arrangement used in table 2. In this table the rocks are broken into four classes, depending on whether perthite is common or rare and undulance is extreme or has given way, in part or whole, to granulation.

TABLE 2

Quartz Undulance and Frequency of Perthite. Data of table 1

Quartz undulance	*Perthite*	
	Common	*Rare*
Extreme	7	4
Moderate or negligible	7	3

Tables 1 and 2 show that perthite is actually rare in only seven specimens, but table 1 does not stress that *in all of these specimens granulation is either incomplete or merely incipient*, and table 2 obscures this relation. It is shown to best advantage in the grouping of table 3.

TABLE 3

Quartz Granulation and Frequency of Perthite. Data of table 1

Quartz granulation	*Perthite*	
	Common	*Rare*
Incomplete	7	7
Complete	7	0

It is possible, of course, that Salisbury was perthitic prior to its deformation—the complete lack of undeformed specimens puts this interpretation beyond refutation—and it is even remotely possible that no specimens in which perthite was rare happened to be so sheared that their quartz was entirely granulated. But it seems more reasonable to accept a relation between shearing and the abundance of perthite as a working hypothesis.

Elberton, Georgia, granite.—Elberton is a fine-grained massive granite which outcrops and has been quarried extensively over an unusually large area in Elbert and Oglethorpe Counties. In virtually every thin section the larger grains of quartz show undulant extinction. The "intensity" of this undulance is usually somewhat greater than in most fine-grained granites, but it never approaches that of the uncrushed facies of Salisbury. In about a third of the specimens granulation of quartz is prominent, but it differs in two important respects from that of the Salisbury granite, described above. In the first place the development of narrow crush mantles about large undulant quartz grains, so characteristic of Salisbury, is virtually lacking in Elberton. Granulation may begin in any part of the grains and spreads haphazardly through them. Secondly, granulation is never com-

plete, as it so commonly is in Salisbury. In every slide some undulance is preserved, and elongation of the granulated quartz masses is much less pronounced. Feldspar granulation, though not rare, is never prominent, even in specimens showing abundant quartz granulation.

The character of the Elberton perthite is also very different from that of Salisbury. In Salisbury, which is a coarse-grained rock, the lamellae are easily visible under low magnification. They are usually string-like, but the strings vary considerably in both length and width, and occasionally they bifurcate. Small microcline grains, or portions of large ones, may thus closely resemble the normal perthite of the alkaline granites. In Elberton, on the other hand, perthite strings are always very slender and are sometimes easily overlooked at lower magnifications. They are much less variable in width, and the members of a particular swarm are usually rigidly parallel to each other. In neither rock do they cross grain boundaries and in both they either terminate at twin planes in microcline or are reflected across them. Because of its finer grain generally and the minute dimensions of the perthitic albite individuals, the crystallographic control of perthite swarms is much more obvious in Elberton than in Salisbury.

Despite these important differences in the habit and fabric of the minerals involved in the comparison, the preference of perthite for portions of the rock in which quartz granulation is most pronounced is quite as strong in Elberton as in Salisbury. Table 4 makes for the Elberton specimens a comparison similar to that of table 3 for Salisbury.

TABLE 4

Quartz Granulation and Frequency of Perthite in Thirty-four Specimens of the Elberton Granite

Quartz granulation	*Perthite*	
	Common	*Rare*
Minor or lacking	1	20
Prominent	12	1

There are two interesting differences between the tables. Whereas perthite is "common" in nearly two-thirds of the Salisbury specimens, it is "rare" in two-thirds of the Elberton specimens. And though perthite may or may not be abundant in Salisbury specimens in which quartz is undulant rather than crushed, it is not common in Elberton unless quartz is

prominently granulated. This second distinction may be laid to the fact that the Elberton quartz tends to granulate before it develops the extreme undulance of quartz in Salisbury. The early stages of granulation in Salisbury generate only narrow, fine-grained mantles about the larger quartz grains; in Elberton there is none of this mantling, and granulation spreads easily and irregularly over the crystals. The crucial part of each table, however, is the lower right-hand box. In Elberton, as in Salisbury, perthite is not rare if quartz granulation is prominent. It is still possible that only perthite-rich portions of these granites were deformed sufficiently to granulate their quartz, but it does not seem very likely.[2]

Other calcalkaline granites.—After completing work on Salisbury and Elberton I re-examined all the granite slides in my collection. In a number of slides the staining of potash feldspar was either too heavy or too patchy to permit reliable estimation of the relative frequency of perthite, and of course the comparison is not worth making unless a fairly large suite of slides is available.

In the granites of Westerly and Bradford, Rhode Island, Fitzwilliam and Milford, New Hampshire, and Pownal, Maine, granulation is rare or lacking and perthite is exceedingly scarce. This is also true of six slides of the Woodbury, Vermont, granite, but in the seventh there is some granulation and a little perthite. In all of these rocks quartz is generally very slightly undulant; the undulance is always less intense than in Elberton and never even remotely approaches that of Salisbury.

In the quartz of the Barre, Vermont, granite, on the other hand, undulant extinction is slightly less pronounced than in Salisbury but considerably more so than in Elberton. Granulation is negligible, and under crossed nicols the Barre quartz looks very like that of Salisbury without the granular mantles. Quartz granulation is prominent in only one slide, and in this slide plagioclase is also moderately granulated. Perthite is common or abundant in nine slides of Barre and rare or

[2] Despite a strong preference for measurement rather than judgment, I have been unable to decide just what should or could be measured so that the attributes of tables 3 and 4 could be transformed into variables. I shall be happy to lend either or both batches of slides to any petrographers willing to undertake comparisons similar to those of the tables.

lacking in twelve. Barre is thus a remarkable parallel to the incompletely granulated facies of Salisbury (see line 1, table 3).

In most specimens of the granite of North Sullivan, Maine, quartz undulance is rather extreme, and in half of them quartz is somewhat granulated though the granulation is never extensive. In most of the North Sullivan specimens perthite is common; perthite strings are usually very fine but they are unusually abundant in the larger microcline grains, where they may also be very long. The longer threads often show wide departure from parallelism in a single swarm. They do not cross grain boundaries and with rare exceptions seem to be deflected by twin planes. Where they are sufficiently abundant the over-all appearance of the grain is that of cryptoperthite.

Bleb and patch perthites like those in alkali granites occur occasionally in other members of the New England suite and are perhaps commonest in certain slides of Woodbury and Milford. In all of these granites it is easy to distinguish between perthitic plagioclase and the much larger euhedral inclusions of that mineral in microcline. The clear albite rims about such inclusions, first noted by Tuttle (1951), are wonderfully developed in Pownal but may be found in almost all calcalkaline granites.

In the Sixmile granites of Llano and the fine-grained granites of the Texas central mineral region generally, quartz undulance is very mild and granulation is rare or lacking. Perthite is also most uncommon. Of some twenty-four specimens of these granites, bleb-perthite is abundant in one, rare in three. No perthite was observed in the remainder. In the coarser Kingsland granite, and in the very coarse Town Mountain granites generally, perthite is not infrequent; these granites contain hornblende in accessory amounts and their quartz is usually conspicuously undulant, though extensive granulation is uncommon. In the coarse Fredericksburg (Bear Mountain) granite quartz granulation is thorough and little undulation remains, though size reduction during granulation was not extreme. Perthite is common in this granite.

In the coarse granite of Mt. Airy, North Carolina, quartz undulance is very weak, quartz granulation is lacking, and perthite is quite uncommon. This is true also of the granites

of Rion, Winnsboro (Anderson), and Blairs, in South Carolina, but in a single specimen from the Estey property, near Winnsboro, multiple twinned patch perthite is abundant though quartz is ungranulated and scarcely undulant; this specimen also carries a little hornblende. The granite of Columbia, South Carolina, is the most extensively mylonized in my collection; quartz is almost entirely granulated and much of the feldspar is also granular. In nine of eleven specimens from this granite, extraordinarily narrow line perthite of Elberton type is abundant. The perthite threads are so narrow that they may often be taken for cleavage traces. With high magnification, however, their refringence and birefringence are clearly higher than those of their host. Where they emerge at the surface of the section they remain unstained. Sometimes they may be detected immediately beneath the section surface by their common optical orientation, which always differs from that of their host.

Summary.—Microscopically resolvable perthite is rare or lacking in granite whose quartz is ungranulated and shows no more than moderate undulance. Examples of this type are Westerly, Bradford, Fitzwilliam, Milford, Pownal, and Woodbury in New England; Winnsboro, Rion, and Blairs in South Carolina; Mt. Airy in North Carolina; parts of the Elberton granite in Georgia; the Sixmile granites of Llano and other similar granites of the central mineral region of Texas. One may hazard the guess that most hornblende-free calcalkaline granites fall in this category.

Where quartz undulance is pronounced but granulation is minor or negligible, perthite may be either common or rare. Examples of this type are Barre, Vermont, North Sullivan, Maine, the Kingsland granite and other granites of the Town Mountain facies in the central mineral region of Texas, and parts of the Salisbury, North Carolina, granite.

Where granulation of quartz is extreme or complete, perthite is usually quite common. The examples described above include Columbia, South Carolina, Fredericksburg, Texas, and parts of the Salisbury, North Carolina, and Elberton, Georgia, granites.

MODAL COMPOSITION OF THE PERTHITIC AND NON-PERTHITIC FACIES OF THREE CALCALKALINE GRANITES

In three of the rocks described above material of both types is common enough to permit useful estimates of average compositions from available thin sections. In all three cases, Elberton, Salisbury, and Barre, the differences between perthitic and non-perthitic facies are very small. The averages are shown in table 5. It is obvious from the table that color

TABLE 5

Modal Composition of Perthitic and Non-Perthitic Facies

SALISBURY

Perthite	Rare Undulant	Common Undulant	Common Granulated
Quartz			
Number of specimens	7	7	7
Quartz	31.2	30.8	31.5
Microcline	26.2	26.5	29.0
Plagioclase	40.5	40.1	37.1
Color index	2.2	2.6	2.4

ELBERTON

Perthite	Rare Undulant	Common Prominently granulated
Quartz		
Number of specimens	20	12
Quartz	28.0	28.8
Microcline	30.8	32.5
Plagioclase	32.4	30.7
Color index	8.3	8.2

BARRE

Perthite	Rare Undulant	Common Undulant
Quartz		
Number of specimens	11	8
Quartz	27.7	27.0
Microcline	19.6	19.2
Plagioclase	34.7	36.1
Biotite	8.2	7.4
Muscovite replacing plagioclase	7.4	7.2
Total muscovite	8.3	8.3
Carbonate	0.8	1.0
Opaque accessories	0.2	0.2
Non-opaque accessories	0.8	0.8

index and quartz content do not vary appreciably and it is interesting to note that this is also true of the Barre muscovite, so much of which replaces plagioclase pseudomorphously. Evidently the sericitization of plagioclase and the appearance of perthite in microcline are unrelated.

Feldspar differences between the granulated and undulant facies at Salisbury and Elberton are suggestive, though not highly significant. If they represent more than sampling variation, granulation seems to be accompanied by a slight enrichment in microcline and an almost equivalent depletion in plagioclase. The appearance of perthitic albite in microcline, however, is unrelated to this composition change, as may be seen in the results for Barre and the first two columns of Salisbury.

PREVIOUS VIEWS OF THE INFLUENCE OF STRESS ON THE FORMATION OF PERTHITE

Perthite is a common rock-forming "mineral" and the literature concerning it is both voluminous and exceedingly complex. The reader will find full reviews in Rosenbusch-Mügge (1925) and Drescher-Kaden (1948), but material germane to the immediate question is easily summarized: stress is commonly regarded as of little importance in the formation of perthite but is assigned a major role in its destruction.

Students primarily concerned with the origin of perthite itself are unanimous in ignoring or giving only passing mention to the influence of stress. This attitude is typified by Drescher-Kaden (1948, p. 142) who invokes "post-crystallization mechanical deformation" only as one means of forming open cracks which are later filled by albite. Drescher-Kaden takes the rather extreme position that the albite filling such cracks is often, perhaps most frequently, a metasomatic introduction. But Mäkinen (1913), who prefers to derive the perthitic albite by exsolution from its host feldspar, is in agreement that the influence of stress is too insignificant to require discussion. In fact, it is only by inference that one can assign it any importance in his work; he regards the net structure or grill of microcline as a response to stresses set up either by dynamic metamorphism or by the transition of orthoclase from monoclinic to triclinic symmetry. And as he insists on a very close relation between the appearance of the microcline grill and the formation of perthite, one may say that he does not entirely ignore stress as a factor in perthite formation.

Mügge (1925, p. 661) thought that the coarser varieties of perthite were formed by recrystallization of cryptoperthite,

the agent of the recrystallization being residual (magmatic) solutions which gained access to the material along the so-called murchisonite cleavage. Though he evidently did not regard stress as directly concerned in either the original unmixing or the recrystallization, he did call upon strong mechanical deformation to enlarge the minute (hkl) partings sufficiently to permit them to serve as channels for the recrystallizing solutions. Mügge thus makes shearing stress a necessary but insufficient condition for the formation (by recrystallization) of all but the finest perthites; its role is only to prepare the way for the villain of the piece. O. Andersen (1928, p. 128 *et seq.*) later showed that the volume relations of quartz and alkali-feldspar were such that considerable cracking of feldspar might be anticipated as a product of cooling alone. Mechanical deformation thus becomes quite extraneous, though Andersen does not specifically discard it. Despite fundamental differences in other respects, these workers, concerned primarily with pegmatites and graphic granites, agree that deformation is of minor importance in the formation of perthite. This view is shared by Alling (1923, pp. 357-58).

In studies whose focus is petrographic rather than mineralogical the origin of perthite is rarely given much notice. The appearance of "stress perthite" in calcalkaline granite seems to have been noted first by du Rietz[3] (1938, p. 21 and fig. 9) in his study of injection metamorphism in the Muruhatten region. Altogether he devotes rather less than a paragraph to the matter. He begins by describing some of the microcline of a strongly granulated facies of Muruhatten granite as ". . . porphyroblastic grains often bent and with uneven perthitic intergrowth due to stress." But he goes on to point out that the plagioclase of this rock has been extensively sericitized and concludes that "A little sodium is hereby liberated producing the myrmekitization of some porphyritic microclines." The possibility that perthitic albite in microcline may have arisen in the same fashion immediately suggests itself, for the distinction between porphyritic and porphyroblastic microcline is far from sharp in most granites and we are already told that the porphyroblasts which contain perthitic intergrowth are themselves mechanically deformed. The usual

[3] Dr. S. J. Shand kindly called this reference to my attention.

alternatives thus present themselves; the perthitic albite may have been derived by exsolution from, or introduced metasomatically into, its host. We are not told whether stress accelerates exsolution (or recrystallization) or merely prepares the way for metasomatic replacement.

The formation of perthite by pressure-induced exsolution in the nepheline syenite of Wasau was suggested long ago by Weidman (1907, pp. 261-63). He finally discards the hypothesis and prefers to leave the occurrence unexplained for the very good reason that there is no evidence of stress in the perthitic rocks. From the description of the perthite, the anorthoclase in question must have been rich in soda and might well have unmixed with slow cooling alone, though Weidman does not consider this possibility.

Two excellent studies of the metamorphism of perthitic rocks suggest that stress, far from favoring the formation of perthite, actually tends to destroy it. Buddington (1939) has found that "non-uniform pressure" tends to dissociate the dominantly perthitic feldspar of various Adirondack pyroxene quartz syenites into discrete crystals of microcline and plagioclase. In general, he concludes (1939, p. 329), ". . . recrystallization of microperthite to albite or oligoclase and microcline has proceeded to the greater completeness in the more completely deformed facies."[4]

The same general tendency of perthite to dissociate under dynamic metamorphism was noted earlier by J. Phemister in the alkaline rocks of Loch Ailsh. Phemister (1926, p. 25) distinguishes four stages in the process by which the initially cryptoperthitic feldspar of the syenites is destroyed, viz:

1. An indefinite patchy intergrowth.
2. The common banded intergrowth.
3. Enclosure of many irregular areas of potash-feldspar in an albite individual.
4. Segregation of small areas of potash-feldspar to form often only a single large patch which may itself enclose a small piece of albite.

[4] With increase in temperature, however, this progressive dissociation may be reversed and the place of ". . . a medium-grained mosaic of microcline and oligoclase" may be taken by ". . . a coarse mosaic of strongly perthitic orthoclase." The recorded field evidence does not seem compelling, however, and it is hard to see how such a transformation could be accomplished without the intermediate step of a homogeneous alkali-feldspar.

He further remarks that "Segregation of perthite into its components is usual in rocks which have undergone recrystallization either as an effect of deformation or because of the presence of hot solutions."

Some rationalization of the rather striking differences between my own conclusions and those of earlier workers is clearly in order. The primarily mineralogical discussions do not eliminate the stress factor and I do not maintain that it is essential, so this part of the argument may be regarded as a draw; presumably if enough albite is present in an alkali-feldspar it will manage to exsolve with slow cooling alone, or perhaps aided by fluxes which are available in considerable quantity in pegmatites and graphic granites. This is not incompatible with the notion that the sluggish exsolution of albite-poor microcline may be accelerated by mechanical deformation and that in the absence of such deformation the metastable phase may persist almost indefinitely.

Buddington and Phemister attribute to stress what seems at first glance an entirely opposite function. The opposition is more apparent than real, however, for both describe rocks in which the original uncrushed material is *already abundantly perthitic*. In their case stress tends to dissociate further an already exsolved perthite containing large amounts of albite; in mine it promotes the exsolution of (optically) homogeneous microcline containing very little albite. In both cases it thus performs a similar function and conflict arises only because in the micaceous calcalkaline granites the dissociation process ends with perthite, while in the rocks described by Buddington and Phemister that is where it begins.

CONCLUSIONS

If the quartz of a micaceous calcalkaline granite shows little or no evidence of deformation, perthite will be rare or lacking. If its quartz is highly undulant but not extensively granulated, perthite may or may not be prominently developed. If its quartz has been extensively or entirely granulated, perthite will almost certainly be common. Even where it is most abundant in rocks of this type, however, perthitic albite is never a quantitatively important constituent; in none of the rocks mentioned above, save possibly North Sullivan, is it present in more than minor accessory amounts. Where it is

prominent it is usually so widely disseminated that if its presence is to be regarded as of species value the potash-feldspar of these rocks should properly be called a mixture of microcline and microcline-microperthite. This is the usage commonly adopted in petrographic descriptions of granite, and it is thoroughly misleading unless the reader is given some hint of the amount—or at least the order of the amount—of perthitic albite involved.

In the statement that perthite may or may not be common where quartz is undulant, the phrase "may or may not" may apply either to entire rocks or to different parts of the same rock. Thus perthite is common in nearly all North Sullivan specimens with highly undulant quartz, rare in nearly all specimens of Elberton with undulant (but ungranulated) quartz, but common in some and rare in other such specimens of Salisbury.

What evidence there is suggests that the appearance of perthitic albite in calcalkaline granites is not necessarily accompanied by changes in modal composition and seems to be independent of what small composition changes may occur in connection with extensive granulation. This is a rather important consideration, for extensive quartz granulation is the surest index of abundant perthite in these rocks and crush zones are favored loci for substantial hydrothermal or other alteration.

If granulation does not function merely by way of providing easy access for mineralizing solutions its association with perthite must be laid to a common cause. In some fashion the shearing stresses which render quartz highly undulant or actually granulate it seem to promote the unmixing of metastable alkali-feldspar (microcline) which otherwise remains optically homogeneous. The effect may be compared to that of vigorous stirring on a slightly supersaturated salt solution, but the analogy should not be pushed too far. It is quite probable that many optically homogeneous granite microclines are already sub-microscopically perthitic, and the effect of shearing may be simply to promote coalescence of the already unmixed albite units. In such cases we should probably regard shearing stress as an aid to recrystallization rather than to true unmixing. To petrographers working without benefit of X-ray spectrometer or on materials un-

suitable for X-ray analysis, however, this distinction may seem rather academic despite its importance.

It is not suggested that all, or even a very large proportion, of perthite requires shearing stress for its formation. Many alkali-feldspars can be unmixed or redissolved in the laboratory by heat treatment alone. But it has often been noted that the time required for thermal unmixing is highly variable, and we may suspect that metastability will be at least partly a function of composition. It may be that alkali-feldspars rich in both soda and potash, such as are common in alkaline granites, unmix rather readily, while the unmixing of compositions close to the potash end member may be very sluggish. As the amount of soda diminishes, the time required for purely thermal unmixing may become large even in geological terms, and the effect of shearing stress in inducing exsolution or enlarging the unmixed units so that they become microscopically resolvable may then be critical. The duration of the shearing stress may also be quite as important as the heating time.

Without much further work, and perhaps even with it, we can not hope to distinguish unequivocally the effects of initial composition, thermal history, or the intensity and duration of shearing stress. The evidence at hand nevertheless strongly suggests that the perthite of the micaceous calcalkaline granites has been formed by exsolution from an originally (optically) homogeneous microcline, and that its formation is favored, if not actually induced, by shearing stress.

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PLIOCENE UPLIFT OF TERTIARY MOUNTAIN CHAINS

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ABSTRACT. Modern tectonic theory, strongly influenced by the Alps, attempts to establish a causal connection between tangential compression (as expressed by folds, faults, and nappes) on the one hand and a succeeding mountain uplift on the other. But Pliocene uplifts of virtually equal magnitude have taken place not only in the Alps, which were tremendously compressed from the Cretaceous to the Miocene, but also in the Pyrenees, strongly compressed but mainly without nappes in the Cretaceous and Eocene, the High Atlas, moderately compressed in the Eocene and Miocene, and the Anti-Atlas, not compressed since the Precambrian. Vertical uplifts of this sort are better considered causally connected with contemporary phases of tangential compression than with preceding phases.

Geological thinking on structural questions in Europe has been influenced to a very large extent by the supposed stupendous shortening of the upper part of the earth's crust in the Alps. Many theories as to the cause and mechanism of mountain-building are based on the tectonic features observed in the central and prealpine belts and have been applied, often unconsciously, to other Tertiary fold-systems, thus arriving at a general picture of mountain-building mechanism supposed to be of worldwide application.

One of the most popular conceptions is that which combines the buckling hypothesis of Vening-Meinesz (1934), which explains the negative anomaly generally accompanying Tertiary fold-systems by the downward buckling of the deeper and main part of the earth's crust, with post-tectonic isostatic emergence of the folded belt. It has been realized from the beginning that the cyclic features of the subsidence and emergence and its often very important retardation still need a lot of explaining, but the general sequence of predicted events is in such good harmony with the morphological features of the Alps that objections to this theory of mountain-building have been rejected as minor imperfections of the theory, or have been answered, as for instance by Umbgrove (1949), in applying this way of thought to the Indonesian archipelago, by a somewhat more complex sequence of folding and emergence. However, if this conception has a more than local value, it should conform to the facts equally well when applied to other and similar Tertiary mountain chains.

In Europe and North Africa there are many mountain chains of Tertiary age, which rise nearly as high above their surroundings, both in the topographical and in the geological sense, as the Alps, and which therefore offer the possibility of checking the value of the buckling-isostatic emergence theory. In figure 1 we compare sections through the Alps, the Pyrenees, and the High- and Anti-Atlas.

The most striking difference between the three sections is the intensity of folding. In the center of the Alpine section we find the recumbent nappes of the Pennines, flanked north and south by a zone of crystalline schists with intruding granite masses of Hercynian age. In the Pyrenees anything like the Pennine nappes is missing, but the center of the section is comparable in structure to the Aar-, Gotthardt- and Orobic-masses, only much less metamorphic. In the High Atlas no central zone of crystalline masses appears. However, if we had taken a section farther west through the High Atlas, the Hercynicum would have been exposed in the center, not as individual masses separated by vertical Mesozoic zones as in the Alps and Pyrenees but by simple arching of the Mesozoic blanket. Both in the Alps and in the Pyrenees some gliding tectonics have occurred from the higher levels into the marginal troughs, but on a much larger scale in the Alps with its complicated set of Helvetian nappes in the north and some gliding nappes in the south. In the Pyrenees we find only occasional gliding nappes on a small scale along its southern border, accompanying upthrusting in the Hercynicum as in the Mount Perdu section. In the High Atlas very little of this kind of structure is known; only in the southern region of Skoura some gliding tectonics have been described. On the whole, the original Jurassic basinlike structure of the High Atlas is still preserved in its present state after two Tertiary folding episodes, witnessing to the gentle character of this folding.

On the other hand there are some striking concurrences between the three sections, as, for instance, the longitudinal fault systems on the margins of the folded belts, which are admirably preserved in the northern Pyrenees, southern High Atlas and southern Alps, but probably largely obliterated in the northern Alps by the intense folding and gliding tectonics.

But we are more interested at present with the younger

movements of the mountain chains than with their tectogenic history. Let us consider first the Pyrenees, which look down on the Aquitanian plain and basin as the Alps look down on the Bavarian plain. The Pyrenees rise to an altitude locally well above 3000 m., somewhat lower than the Alps, a difference due to their much narrower structure. As in the Alps the Mesozoic cover has been removed from the central zone, hence their elevation is perhaps of the same order. Admirably preserved post-tectonic erosional levelling surfaces witness to the original low altitude of the folded chain and to later elevation (Faucher, 1934; Birot, 1937; Goron, 1941). In figure 2, for instance, the plateau at about 900 m. altitude, deeply dissected by younger rivers, represents the end of a Tertiary denudation period of probable late Miocene age, which truncates vertical Paleozoic and Cretaceous strata. In figure 3, a similar pause in the upheaval of the Pyrenees is represented by the Esplas plateau. Both examples are taken from the north-Pyrenean zone in which large Paleozoic domes with their Mesozoic mantles are separated from one another and from the axial

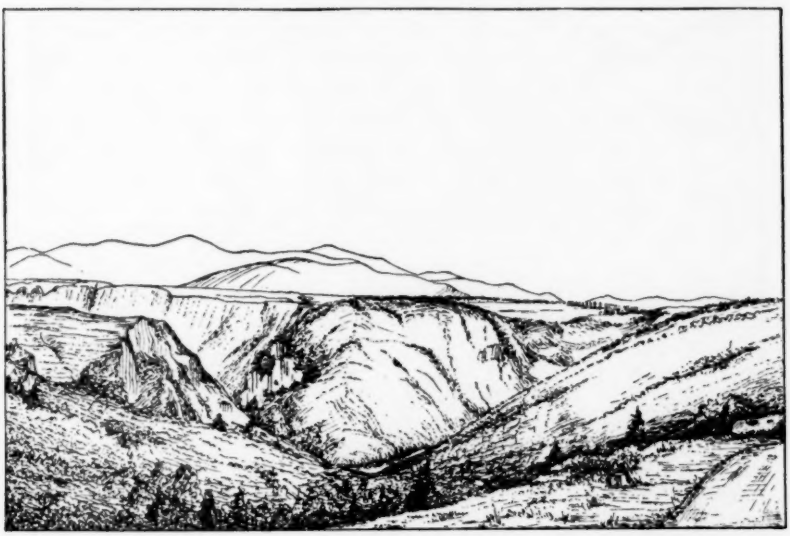


Fig. 2. Pyrenees. The Pays de Sault aplanation surface, Pliocene?, altitude ± 900 m., with the Rebenty canyon, looking towards the south. The peneplain truncates Mesozoic and Paleozoic vertical strata exposed in the canyon.

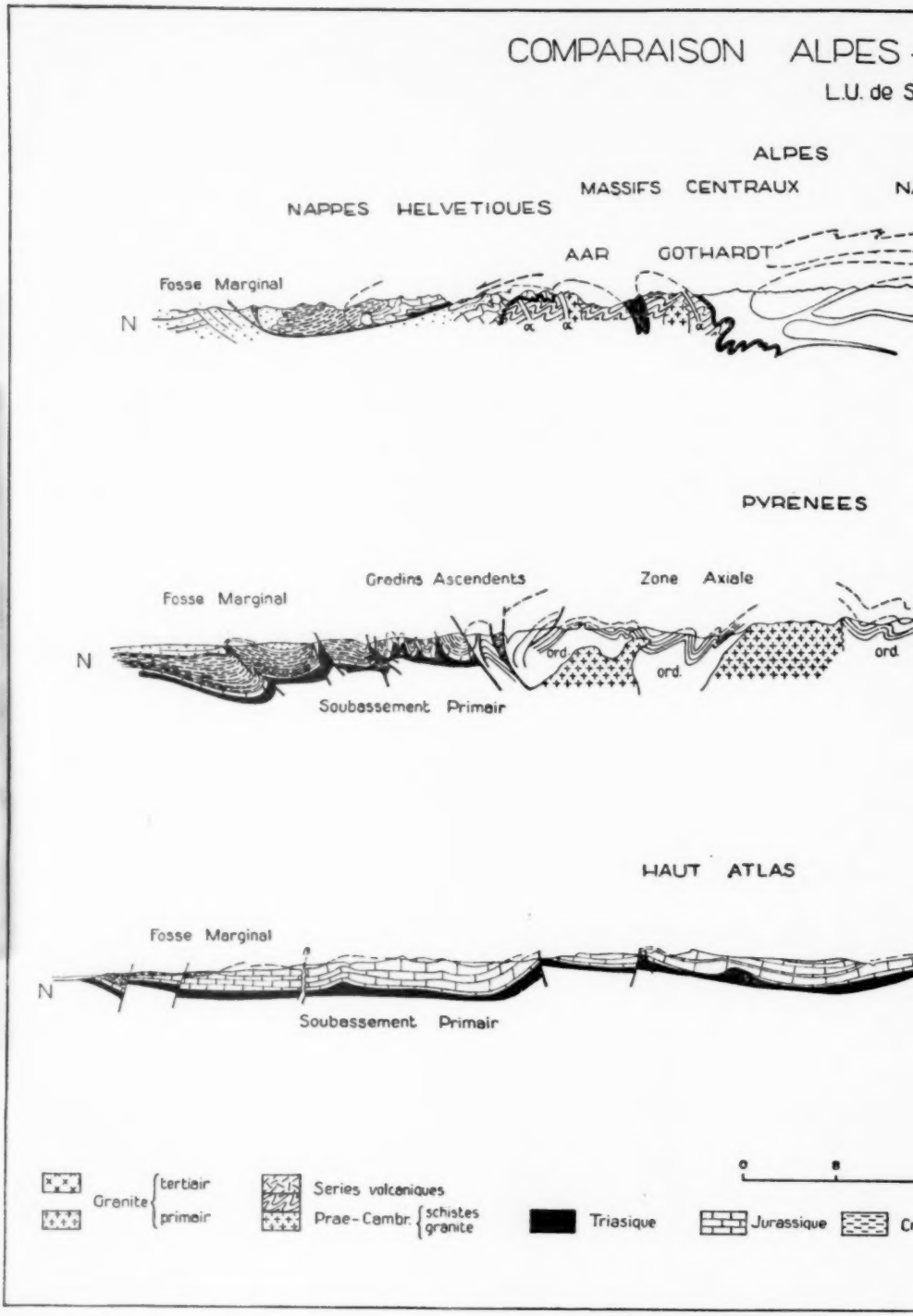
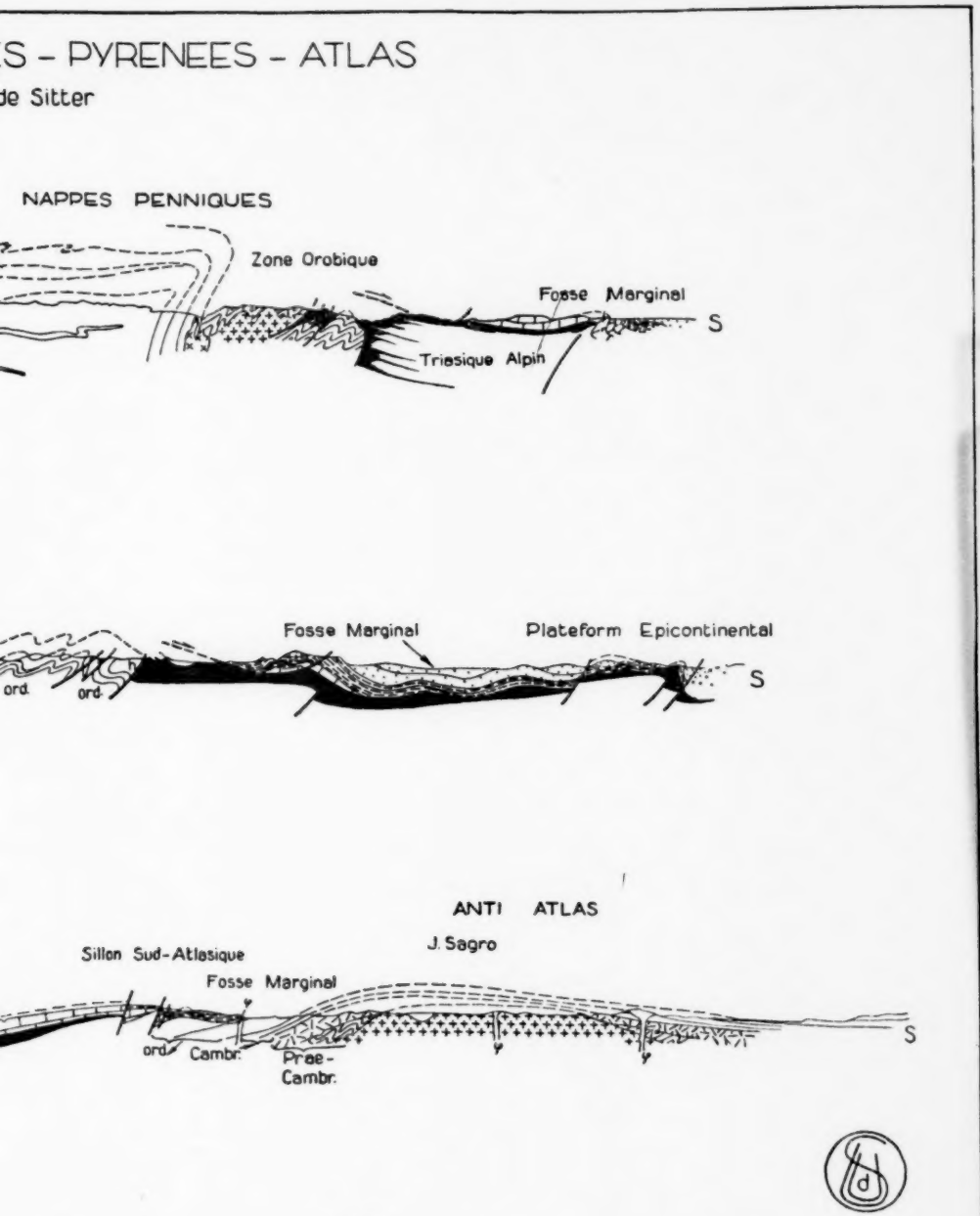


Fig. 1. Structure sections across the Alps, t



ps, the Pyrenees, and the High- and Anti-Atlas.

zone by vertical, narrow, and strongly compressed Mesozoic belts. The Tertiary aplanation surfaces continue, however, in the axial zone, where for instance the "plate-forme d'Aston," at an altitude of 1800 to 1900 m., south of the longitudinal east-west Ariège valley between Tarascon and Ax-les-Thermes along such a Mesozoic vertical belt, rises slowly towards the central divide. On its broad back it carries mountain peaks, remodeled by Quaternary glaciers, which, however, do not rise more than 600 or 700 m. above its level. The Aston surface also has a Miocene age; it is still discernible at the other side of the Ariège valley and therefore is post-tectonic.

By the end of the Miocene the Pyrenees represented there-

Fig. 3. Pyrenees. The pre-Aquitanian (?) aplanation surface, altitude ± 800 m., preserved in the Massif d'Arize near Esplas and Montagnon; in the background the top ridge of the Massif d'Arize. The steep canyon is the higher Arize valley, all in Paleozoic rocks.

fore a gently undulating, very mature landscape, almost a peneplain with low hills, which in the center did not rise above 1000 m. altitude. Since then, and before the Quaternary glaciations, the upheaval elevated the center at least 2000 m., tilting the Miocene aplanation surfaces, which now slope gently towards the north. This history is in all respects comparable to that of the Alps.

The great difference from the Alpine chain lies, however, in the pre-upheaval tectonic history. The Tertiary folding of the Pyrenees was finished by the end of the Eocene, whereas, in the Alps, Miocene and Pliocene phases are important. Not only is the age of the folding quite different, but also the character of the folding. In the Pyrenees we find nothing of the kind of large thrust sheets, neither of the Penninic type nor of the Helvetian type. (In the southern marginal zones we find a series of gravitational gliding structures, the largest being the cascade folds of Mount Perdu.) In the center there has been a strong compression of longitudinal blocks, large "plis de fonds" between which the Mesozoic mantle in the synclines has been strongly compressed and often metamorphosed, and in the foothills we find long superficial structures of moderately folded Mesozoic and older Tertiary strata. The total meridional shortening is therefore only a fraction of that of the Alps. There is hardly any evidence of recrystallization in the Paleozoic strata down to the Ordovician, there are no nappes, and the whole tectonic development ended in the Eocene, but the large Pliocene epeirogenetic movement which elevated the present mountain chain is of the same age and the same magnitude as that of the Alps.

Let us now turn our attention to the southern border of the Tethys geosyncline, to the great mountain system of the Atlas.

The High Atlas again reaches well above 3000 m. in its highest peaks. The Tertiary folding is of Eocene and Miocene age, the upheaval much younger.

In the Atlas we find again, as in the Pyrenees, folded longitudinal blocks, but with much less compression. On the south side of the western High Atlas the Cretaceous, directly overlying the Triassic cover of the Paleozoic, rises gently and continuously, broken only by an occasional fault, towards the center, where only strongly compressed Paleozoic is

exposed. The same is true of the northern flank of the mountain chain, where long and almost horizontal Lower Eocene escarpments lie on top of the foothills, formed by Cretaceous on Triassic strata, unconformably overlying the folded Paleozoic.

Farther east the Jurassic cover is either moderately folded in sharp anticlines and broad synclines of the surface type (fig. 4) or unfolded and gently sloping southwards, on a southern block (fig. 5).

A Pliocene upheaval is very evident and has given rise to intensified erosion in the Quaternary (Choubert, 1949). To a large extent, the inner valleys of the eastern High Atlas still have their Pliocene geography with very large synclinal valleys (fig. 4), although many of the "cluses" leading through the Lower Liassic cores of anticlines probably have a Quaternary origin due to the tilting of the whole block. In the southern slope deep ravines have been cut since the Pliocene upheaval (fig. 5).

Still farther south the edge of the Sahara block has been slightly folded in the Anti-Atlas Mountain chain. Precambrian

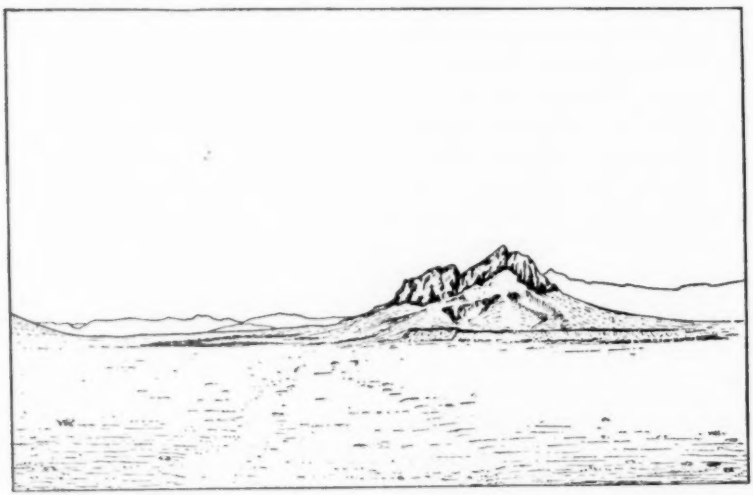


Fig. 4. High Atlas of Morocco. The plunging anticline of Bau Hamid with a hard Lower-Liassic limestone core and softer marly limestones of Upper Lias in the flanks. The river Ziz curves round the nose of the anticline. To left and right the broad synclinal plains are cut in soft Dogger marls. Pliocene landscape of the center of the High Atlas.

rocks crop out in the core of the large dome of the Jebel Saghro, disconformably covered by the Lower Cambrian which shows dips not exceeding 30° and generally much less than that. The center of the dome is occupied by a Pliocene plateau modeled in granite and schists of the Middle Precambrian on which occurred phonolitic extrusions in the Pliocene. This central plain lies at about 1900 m. altitude and is dissected only on its borders where young river systems have cut deep gullies in granite and late Precambrian volcanics. There the same Pliocene phonolites are found now only on the tops of mountains at the same altitude of about 1900 m., sometimes preserving at their base Pliocene lake deposits (fig. 6). The history of this Anti-Atlas chain can therefore be reconstructed as a levelling of the very gentle Hercynian folding, in Mesozoic and Tertiary times, followed by lake deposits and phonolite flows in the Lower Pliocene on Precambrian and Cambrian rocks, then upheaval of at least 1000 m. in the Pliocene and renewed erosion since then.

Our review has shown that a Pliocene upheaval of 1000 to

Fig. 5. High Atlas of Morocco. The canyon of the lower Ziz between Kerrando and Ksar es Soukh in unfolded Upper Lias. Post-Pliocene erosion.

2000 m. occurred as well in the Alps, the Pyrenees, the High Atlas and the Anti-Atlas. The tectonic history of these mighty mountain chains is, however, widely different: extreme compression in the Alps in successive stages since the Cretaceous and including the Miocene, strong compression in the Pyrenees in the Cretaceous and Eocene, moderate compression in the Eocene and Miocene in the High Atlas, and no compression in the Anti-Atlas.

Whereas in the Alps the isostatic upheaval of a mountain root is an adequate explanation of the Pliocene emergence, it is less so in the Pyrenees where the time interval is much greater and the evidence of a root much smaller; in the High Atlas a buckling down of the deeper crust is hardly conceivable, and it is certainly absent in the Anti-Atlas. The Pliocene upheaval is of the same order in all four mountain chains.

Hence there is no evidence to support the theory that younger Tertiary upheaval is a consequence of the older Tertiary compression; on the contrary the two phenomena seem to be wholly independent when seen from this point of view. Epeirogenic and tectogenic movements may have a common cause but the one need not be the consequence of the other.

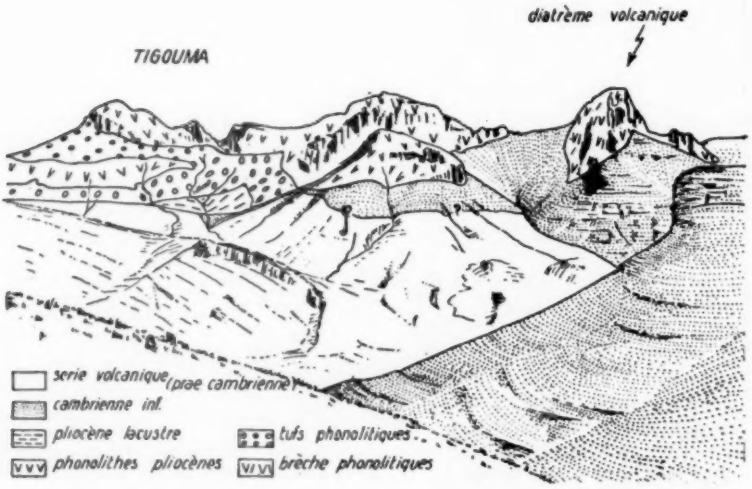


Fig. 6. Anti-Atlas of Morocco. Pliocene phonolites on top of the Tigouma in the Jebel Saghro, Anti-Atlas, disconformably overlying Precambrian volcanics and Lower Cambrian sandstones. Altitude ± 1900 m.

Both Escher (1948) and Fourmarier (1950) use the term "tectogenetic" as opposed to "orogenetic," the former indicating "true" tectonic structures, folds and faults, the latter indicating the upheaval of the already folded belt, the truly mountain-building movement in the orographic meaning of the word. The causal connection between tectogenesis and orogenesis is, however, often obscure, and the time interval between the two occurrences has to be taken carefully into account.

In this respect we may recall a similar situation where two separate movements have been ascribed to one cause, but where again the time interval makes us hesitate to accept the theory. According to the fascinating theory of H. Cloos (1929, 1932), the upper Rhine rift valley and its northern continuation in the Cologne embayment is due to the arching of the Rhenish shield, the arching causing tension in the upper part of the crust and hence the formation of the normal faults and the subsidence of the central block. Again we are concerned with a theory combining two structural phenomena, the arching of the shield and the subsidence of the rift valley, and again the theory is contradicted by the time the events occurred. In this case the subsidence ought to be contemporaneous with the arching, but this is certainly not the case; a considerable time interval separates the two events. In the Cologne embayment, for instance, we know that the central portion of the arch was already elevated in Cretaceous time and the rift occurred only in the Miocene. In the upper Rhine valley the subsidence started earlier, in the Oligocene, probably in connection with the strong Oligocene folding phase of the Alps.

Anyhow the tangential movements and vertical movements during a mountain-building period are often very complex, and the two phenomena can seldom be separated logically as individual phenomena, each having its own cause and mechanism, except in the cases we have described, where a later upheaval occurred after a considerable time interval. Without doubt there are in the Alps many instances of direct vertical movements which occurred intermittently between the folding phases. In the southern Alps, for instance, the general structure consists of a series of broad steps, separated by vertical zones or faults, leading up to the Orobic crystalline zone (de Sitter, 1949, 1950). The structure of the Triassic strata of a lower step shows that they have been compressed against the vertical

wall leading to the next higher step, and on the other hand the same strata have glided down along appropriate weak strata from a higher step onto a lower step. Hence some of the compression took place after the upheaval of the steps and some of the folding occurred after this vertical displacement.

The uplifted Pliocene surface has perhaps received undue emphasis, because it is the latest and best preserved from ravages by Pleistocene glaciation. Any tectogenic belt is characterized by alternations of strong compressions and positive and negative vertical movements.

When we perceive that the large amplitude Pliocene movements of High- and Anti-Atlas coincide exactly in time with an extreme paroxysm of the Rif Mountain chain, and the Oligocene sinking of the Upper Rhine rift with one in the Alps, I prefer to see these coincidences as a causal connection, instead of accepting a purely hypothetical theory that does not establish such time agreement. This does not imply that I would reject altogether the theory of buckling and isostatic adjustment for the Alps or the Indonesian archipelago—on the contrary—but the supposed causal connection between the two different structural events does not have general application.

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Leiden, Holland

OBITUARY

HERBERT E. GREGORY (1869-1952)

The passing of Herbert Gregory on January 23, 1952, closes the active career of a noted and colorful figure from the ranks of American geologists and geographers. He died in his beloved Hawaii, which had been his home for the last 30 years.

Gregory was born in Middleville, Michigan, October 18, 1869, and in the fullness of time entered the Class of '96 at Yale with advanced standing, graduating with that class which gave several of its members to the Yale Faculty for long and distinguished service to their Alma Mater. Gregory took his Ph.D. in 1899 and immediately thereafter was appointed an instructor in physical geology. He was promoted to the rank of Assistant Professor in 1901, and was made Silliman Professor of Geology in 1906, a title he retained until he became Emeritus in 1936.

According to an agreement between Yale University and the Bishop Museum by which the presiding officer of the latter became a member of the Yale faculty if he was not already such, Gregory was appointed Acting Director of the Museum in 1919, Director in 1920, and Director Emeritus in 1936. By the terms of the original agreement the Director of the Museum was to spend part of each academic year in his professorial capacity at Yale. This Gregory did for a number of years before relinquishing his professorial periods when his permanent residence in Hawaii was established.

Gregory was not content with filling these two offices with their exacting duties but extended his influence and activities to other fields, notably as assistant and later (1909) geologist of the United States Geological Survey. In this connection he was for some years concerned with the problem of "finding water for the poor Indians," as he expressed it, especially the Navajos of Arizona, New Mexico, and Utah. Later he did extensive field study and mapping in the vicinity of Zion National Park and neighboring parts of the Colorado Plateaus. Of several resulting publications, one appeared shortly before his death.

The years 1916 to 1920 found Gregory serving as Super-

intendent of the Connecticut Geological and Natural History Survey; then his interest turned largely to the Pacific, with headquarters in Hawaii, although he still returned to the continent for his summer work in southern Utah.

The establishment of the National Research Council gave Gregory an additional duty in the Division of Geology and Geography and from 1920 to 1946 he served as chairman of the Committee on Pacific Investigation, becoming chairman of the Pacific Scientific Council in 1946. He was also chairman of the Board of Regents of Hawaii and a member of the Yale Expedition to Peru in 1912 and 1913. Thus Gregory's interests covered a wide geographical area—Connecticut, Arizona, Utah, Peru, Hawaii, and the Pacific Islands, as well as Australia.

Several learned societies, the American Academy of Arts and Sciences, the American Philosophical Society, and the Geological Society of America, among others, welcomed Gregory to their fellowship and he served the last as councillor and Vice-President.

This venerable publication, the American Journal of Science, founded by Silliman in whose honor Gregory's Professorship at Yale was established, bore Gregory's name on its cover as Associate Editor for 24 years, from 1904 to 1928. The Journal reveres his memory and offers this inadequate tribute to a loyal and eminent man.

R. S. Lull

REVIEWS

Some Recent Researches in Solar Physics; by F. Hoyle. Pp. x, 131. London and New York, 1949 (Cambridge, University Press, $3.00).—The aim of this monograph, which appears in the series "Cambridge Monographs On Physics," is said to be to provide a concise account of the present state of solar physics. However there is no discussion of the deeper layers of the solar atmosphere, the structure of which has become well understood only quite recently. Although these matters have been adequately reviewed in the astronomical literature, their omission from a monograph intended to reach physicists at large, perhaps, is regrettable. Throughout the book has a strongly personal flavor, and more than one third of it deals solely with a theory by Hoyle and Lyttleton, which tries

to explain the chromospheric and coronal phenomena in terms of accretion of matter from interstellar space. The remainder of the book is devoted to solar magnetism, solar and terrestrial relationships, and radio emission from the sun.

RUPERT WILDT

Our Sun; by DONALD H. MENZEL. Pp. viii, 326. Philadelphia, 1949 (The Blakiston Company, $4.50).—This new addition to the well-known series, "The Harvard Books On Astronomy," clearly and vividly tells the story of our sun in the words of one of the most active solar physicists in this country. It will delight laymen and astronomers alike, though it is not always apparent just whom the author is addressing. Readers requiring instruction on the nature of the spectroscope and the atom will hardly be able to appreciate many of the excellent illustrations of instruments for solar research and of the records obtained by them. The book is not free from minor errors. The author's flair for popularizing science, in the best sense of the word, is notable.

RUPERT WILDT

Modern Interferometers, by C. CANDLER. Pp. 502. London, 1951 (Hilger and Watts, Ltd., $9.75. In U.S.A.: The Jarrel Ash Company, Boston, Mass.).—Measurements made with interferometers are among the most accurate made by man. With an interferometer one can measure a length to 10^{-12} of a centimeter, separate the "hyperfine" components of a spectral line, measure the diameter of a star, and do many other impressive feats. Applications of interferometry are to be found today in almost all of the branches of science and technology.

This volume is a comprehensive treatment of the instruments of interferometry, with inclusion of only such theory as is essential. Every type of interferometer is described, including the diffraction grating. The bibliography is complete and the diagrams and illustrations are excellent. Since the publisher is also a leading manufacturer of this type of equipment, the authoritativeness of this book is guaranteed.

W. W. WATSON

The Phase Rule and Heterogeneous Equilibrium; by JOHN E. RICCI. Pp. xi, 505; illustrated. New York, 1951 (D. Van Nostrand Company, Inc., $12.00).—To the geologist and metallurgist, as well as to the chemist, one of the most interesting branches of physical chemistry is the study of heterogeneous equilibria. Many experimental investigations have been made of the phase relation-

ships of pure substances and of mixtures, and several books have been devoted to analysing and classifying the data. Although the basic ideas are relatively simple, their application to multicomponent systems can become extremely involved. Unfortunately, it is just these systems which are of most interest to the geologist, and to the others who wish to apply the results of phase rule studies.

Professor Ricci has recognized this fact, and has devoted more than half his book to ternary, quaternary and quinary systems, with even a few remarks on the application of the methods to six-component systems. The treatment is entirely general, and no attempt is made to catalogue the various systems which have been investigated. Although many actual systems are used as examples of various types of behavior, they are selected because of their illustrative value, and not because of their practical importance.

Perhaps the most distinctive feature of the treatment lies in the consideration of complete miscibility in the solid phase as the norm, with partial and nonmiscibility, and compound formation as variations. Although from this viewpoint many of the most familiar systems appear unusual, the helpful analogy between liquid and solid phases is emphasized. The stress on solid solutions will also appeal to mineralogists and petrographers in view of the prevalence of this type of behavior among minerals.

Considerable attention is spent on clarifying the finer points involved in the interpretation of the phase rule, although some might disagree with the conclusions drawn. There certainly has been much confusion on these topics in the past.

Great pains have been taken to make the discussion as clear as possible. About 520 diagrams, some of them in several parts, are included. A helpful device is the use of standard orthographic projections for the diagrams of two-component systems to emphasize the relations between the constant-temperature and constant-pressure representations ordinarily considered.

In spite of the effort which has been expended to explain the subject, both by word and by diagram, the book is still difficult reading. It may be that the graphical presentation so useful for one and two-component systems, and adequate for three-component systems is not powerful enough to cope with systems of higher order, and that new analytical tools must be adopted before the treatment of systems of this type is entirely satisfactory. Although the steps in this direction are so far only tentative, it is unfortunate that Professor Ricci did not refer to the work of the few authors who are attempting to follow Gibbs in progressing from geometric to analytic reasoning in the description of heterogeneous equilibria.

The printing and binding are up to the usual standards of the publisher. Only a few trivial errors in proof reading were noted. It is unfortunate that the cost is so great that few individuals will feel justified in adding this book to their personal libraries.

HENRY C. THACHER, JR.

The Biochemistry of Fish; edited by R. T. WILLIAMS. Biochemical Society Symposia No. 6. Pp. 105. London and New York, 1951 (Cambridge University Press, $2.75).—This pamphlet contains a collection of general papers which should serve to point the way for increased attention in this neglected field. R. A. Morton introduces the symposium which is opened by a short paper by E. Baldwin entitled "Some Comparative Aspects of the Biochemistry of Fish." The familiar aspects discussed here are osmotic relations to the environment, distribution of nitrogenous bases and the vitamins A, and the excretion of nitrogen. G. Hamoir, in his paper, "The Proteins of Fish," presents a masterly discussion of the proteins from fish skeletal muscle. J. M. Shewan assembles a timely review concerning the chemistry and metabolism of the nitrogenous extractives in fish. He notes that the origin and the physiological role of trimethylamine oxide is still very much in doubt; it is highly possible that trimethylamine oxide may be exogenous. It has been of concern to this reviewer that marine teleosts may excrete three methyl groups per atom of nitrogen even though it is known that the mammal, at least, may suffer from a dearth of such labile methyl groups. Fat from fish contains glycerides of even-numbered fatty acids from C_{14} to C_{22} as compared with the monotonous preponderance of C_{16} and C_{18} acids in higher animals. J. A. Lovern in his excellent paper entitled "The Chemistry and Metabolism of Fats in Fish" ends his discussion by pointing out that the complexity of fish fat enables the investigation, by detailed fatty acid analysis, of the enzyme systems which produce and modify the fat. T. H. Goodwin writes an able discussion of the distribution, formation, and functions of carotenoids in fish. G. A. D. Haslewood presents a short paper on the bile salts of fish and C. L. Cutting concludes the symposium with a paper entitled "Economic Aspects of the Utilization of Fish" which in general brings to the forefront the legion problems of the fish industry. Some idea is given to the biochemist how his work may be applied to fisheries' problems. To anyone interested in the subjects of comparative biochemistry or, needless to say, fisheries biochemistry these one hundred pages are a welcome addition to his all-too-sparse library.

WARREN H. YUDKIN

Physical Geography; by ARTHUR N. STRAHLER. Pp. vii, 442; numerous figs. New York, 1951 (John Wiley & Sons, Inc., $6.00).—On two counts this book must be given high praise. In the first place, it is a fine piece of craftmanship. Professor Strahler has done an excellent job of selecting the most significant items from the wide range of topics he covers. He has woven them into a readable and, one feels sure, teachable book. The illustrations are very good. Nearly all the diagrams are large and clear and make their points effectively. Specialists, to be sure, are likely to find inadequacies or even inaccuracies in the parts of the book dealing with the topics with which they are most familiar. The reviewer, for instance, regrets to read that "Wind . . . follows the general direction of the pressure gradient." In spite of this and similar criticisms, Strahler has gone surprisingly far into explanations in view of the limitations of space.

A second praiseworthy feature of the book is that it succeeds in carrying one along remarkably well from one branch of physical geography to another. Physical geography should not be a series of unrelated earth sciences but, rather, the study of the interrelated physical elements that coexist on the earth. Because the author assumes no background and because the human mind, especially in its undergraduate stage of development, has its limitations as an integrator, the book necessarily proceeds from one element to another. But the author has used the study of maps as a bridge between the study of the globe and the study of landforms and has wisely, in the reviewer's opinion, placed the solid earth ahead of the insubstantial air. Soils, the product of earth, water, air, and life, form a logical conclusion.

If one looks at the book in a larger way, one is seized by certain pangs. For these the author is in no way to blame. The fault lies in American elementary and secondary education. It is distressing to think that the teaching of the physical elements of geography in the elementary and secondary schools is at such a low ebb that a professor in one of the leading universities finds it necessary to begin his course with proof of the earth's sphericity and to explain in detail the difference between latitude and longitude. Yet this bears out the experience of all American teachers of college geography and the findings of the New York *Times'* survey reported in June of this year. Much of what is in this book should be part of the knowledge of every college entrant but, because it is not, many college teachers will find this book useful.

STEPHEN B. JONES

A Textbook of Geology; by ROBERT M. GARRELS. Pp. xvii, 511. New York, 1951 (Harper & Brothers, $5.00). In this new textbook

of geology, an attempt is made to break away from what is now the "standard" presentation of elementary geology in textbooks, and to develop the subject matter as far as possible quantitatively instead of qualitatively, analytically instead of descriptively, and by use of the reason instead of by weight of authority. Garrels himself says at the outset: "The differences between this ideal and the text as it actually emerged are obvious and even alarming." But he adds: "But incomplete as the realization of the ideal may be, it should be attempted;" and this reviewer thoroughly agrees. No subject, whether at the level of advanced research or of the most elementary teaching, should be allowed to stand still, and there is moreover considerable agreement on the general nature of the changes needed at this particular time in the teaching of elementary geology (see the reports of Conferences on Training in Geology in the Interim Proceedings of the Geological Society of America for 1946 and 1947; also the review of a new edition of a standard text by J. W. Peoples in this JOURNAL, vol. 248, pp. 73-75). But to carry through such changes requires not only considerable boldness but a very great deal of hard work, pioneering work in the recasting of traditional material or the presentation of new material at the elementary level.

Garrels and his colleagues have begun this hard work while teaching the elementary course in geology at Northwestern University, experimenting with the material and trying to inject here and there and throughout the new kinds of emphasis; this textbook is the result. This reviewer, heartily in sympathy with the purpose of the book, has mixed feelings about its success in achieving that purpose. To him it seems almost like a progress report. Some important successes may be listed: the wide use of graphs, even when they must be largely qualitative for lack of data; the attention to the physics of the processes discussed, especially the gradational processes; the introduction of model theory; the conscious effort to separate individual variables in the analysis of complex processes such as land sculpture (though the concept of the "perfect land surface" is hardly as new as the author implies). On the other hand the book seems less successful in its avowed attempt to have the student work out for himself as he goes along the geological principles and conclusions he needs. Again and again the development has to be interrupted to introduce material "on authority" because it is needed at once but cannot yet be developed by the student. At times, such material is introduced only parenthetically and from the textbook alone would hardly be clear. For example, the concept of mass-wastage, needed in the discussion of

land sculpture by streams, is introduced in one paragraph on page 49 which, while technically correct, is so general as to be meaningless to a student who has only reached Chapter 4 in his first book on geology, yet the concept is used steadily from that point on without further explanation. But perhaps such defects are less serious than appears at first sight, for of course the textbook is not to be used alone but in conjunction with a teacher, who can expand on such points as far as the student is equipped to follow. Indeed, many parts of the book give the impression of being part of the outline of an able lecturer — some points fully worked up, others only sketched because the lecturer intends to fill them out in lecture or discussion.

In sum, the book is not one for lazy students; the mixture of the authoritarian and analytical approaches would only confuse them, whereas it should stimulate (and also exasperate) the able ones. Likewise it is no book for lazy teachers; it will raise, at least among the better students, more questions than it answers (in part by design), and only teachers of ability can meet the challenge. But all elementary geology teachers (and textbook writers), whether or not they intend to use such a book or such an approach, should study it with care, for both its successes and its relative failures are full of instruction and point the way toward the ideal of a textbook which Garrels has set himself. JOHN RODGERS

Applied Sedimentation, A Symposium; edited by PARKER D. TRASK. Pp. xi, 707; 22 tables, 116 figs. New York, 1950 (John Wiley & Sons, Inc., $5.00).—The purpose of this book is to call attention to the ways in which the growing science of sedimentation may be applied in the fields of geology and engineering. Every geologist has been more or less aware of the data which are presented here, but I think everyone will admit surprise at the amount and variety of material that has been quietly accumulating over the years. The value of this symposium lies in presenting in a single volume the many facets which one of the newer branches of geology has acquired, and in pointing out how useful a tool it has become.

The book has seven divisions. Part 1 takes up the basic principles of sedimentation. Dynamics from weathering to diagenesis together with their environmental controls is treated first. Then come chapters on specific problems: the origin of the soil profile, transportation, geophysical problems with respect to sediments, soil mechanics and its geological applications, and the occurrence and recovery of ground water with respect to different sedimentary environments. All of these topics are approached from the geological

angle with one exception, the chapter on soil mechanics. It explains that branch of civil engineering to the geologist and as such should serve a very useful purpose in pointing out the many techniques that the geologist may borrow from this rapidly expanding field.

Sediments from the engineer's point of view are considered in part 2. He differs from the geologist in his approach in that he regards sediments as building and foundation materials only, and is not at all concerned with their environments and past histories. What he can or cannot do with them is the important thing, just as with steel, concrete, wood or any other building material. A knowledge of the strength and behavior of sedimentary materials is important in highway construction, in foundation problems of all kinds, as well as in building dams and levees. The special problems of tunneling in soft ground are also described. This section serves to stress that the engineer and the geologist have not taken full advantage of what the other has to offer, and that they can be mutually useful to a greater extent than has been true in the past.

Part 3 discusses how various sedimentary processes affect man and his works, and what practical means can be employed to control or modify them. The topics considered are landslides, permafrost, beach erosion, silting in harbors, reservoirs and irrigation canals, stream channel control, the value of model studies in the analysis of all sorts of shoaling problems, and lastly the serious erosional problems that have arisen with regard to agricultural and grazing lands. The practical solution of these natural processes is of great economic importance and has a very important bearing on the future resources of the country as a whole. The undesirable aspects of many of them can never be entirely eliminated but much can be done by way of control.

Part 4 describes the nature of the sedimentary constituents used in various industrial processes. A cheap and plentiful supply of the right kind of aggregate is essential in making concrete. Thorough study of the composition and characteristics of the various clay minerals is essential before any one can be recommended as source material for a specific purpose in the rapidly expanding field of ceramics; and furthermore, each clay deposit must be individually examined as the varying percentages of the different clay minerals must be determined. In foundry practice the cohesiveness, resistance to heat, permeability, compressive strength, volume change with temperature, and the texture of the molding sands must be known in order to turn out suitable castings. A sedimentary background is important in locating deposits of material which will meet the requirements for all three processes mentioned above.

Part 5 considers the importance of sedimentary rocks in economic

geology. The rather minor role that the geologist now plays in the search for new sedimentary mineral deposits as well as in the extension of old ones is discussed, with suggestions for putting his abilities to better use. Sedimentary iron ores are taken up in some detail. This is followed by a chapter describing the different types of residual concentrations, veins and replacements so commonly found in consolidated sediments. The section concludes with a chapter on the geochemical prospecting methods now commonly praticed.

Part 6 briefly discusses a few of the problems of petroleum geology which involve sediments. Obviously a discussion covering the whole field would fill a book larger than the present one. The topics selected include subsurface techniques in which the various types of logging are described, and work on the actual cores themselves, texture, micropaleontology, heavy minerals, and finally subsurface correlation are touched on. Porosity, permeability and the capillary properties of reservoir rocks occupy the next chapter and receive a very thorough treatment. The rather specialized problems relating to the porosity and permeability of limestones and dolomites are described in the last chapter. The need for the development of techniques for secondary recovery such as have been so successfully employed in the sandstones is stressed.

The final section concerns itself with the importance of sediments and sedimentation in military operations. These applications were principally developed during the last war. Problems of terrain have been more or less appreciated by the military from the beginning of antiquity but modern mechanized armies are faced with additional problems. Trafficability, which involves the movement of many types of vehicles on many types of terrain, water supply for the large numbers of men involved, and construction materials for the greatly expanded engineering operations, of which air field construction is one, have all entered the picture. On the naval side the "applications of the study of sediments . . . are much broader than might be inferred from a strict interpretation of the term sedimentation." Much was learned specifically about submarine geology and in fact the whole problem of sediments and sedimentation in the sea is so inextricably bound up with the broader problems of oceanography that a general understanding of the latter is essential.

The many authors, and especially the editor, are to be congratulated on the comprehensive picture which they have presented, and also for welding the material into a treatise which hangs together. Such unity is rather remarkable when one considers that each article was written independently. Each author shows a keen

appreciation of the problems yet to be solved, and all of the chapters either conclude with a statement emphasizing the need for further research, or call attention to this point somewhere in the body of the text. This should not be taken as an indictment of the present inadequacies of the science of sedimentation itself, but rather as an estimate of the future development of which this branch of geology is capable.

H. C. STETSON

An Introduction to the Study of Organic Limestones, revised ed.; by J. HARLAN JOHNSON. Colorado School of Mines Quarterly, vol. 46, no. 2, Pp. 185, 1 text fig., 104 plates, Golden, 1951 ($2.00). Originally published in 1949, this booklet differs from the previous edition by inclusion of chapters on worms and arthropods and the addition of 45 new plates. Without minimizing the value of purely lithologic and chemical studies of limestones, the author here devotes his attention principally to the organic contents of such rocks. His purpose is to provide illustrations and descriptions of both the megascopic and microscopic aspects of the plants and animals whose remains or effects contribute largely to the making of calcareous strata. The ultimate intent is to help the student to identify such fossils.

The book is arranged in chapters running, according to the usual taxonomic scheme, from Foraminifera to Arthropoda, with a final chapter on the Calcareous Algae. The organisms are well illustrated and 19 tables give typical chemical analyses of them. Much of the material is that studied by the author in connection with his investigations of the calcareous algae occurring in the so-called coral reefs of the Pacific Islands. Each chapter concludes with a set of pertinent bibliographic references. The student should find this book helpful in orienting himself before proceeding to more detailed identifications.

ROLAND W. BROWN

Crystals and the Polarising Microscope, A Handbook for Chemists and Others, 2d ed.; by N. H. HARTSHORNE and A. STUART. Pp. xii, 473; 312 figs., 1 folding plate. London, 1950 (Edward Arnold, 50 s.); New York (Longmans, Green, and Co., $9.50).—The first (1934) edition of this book was written primarily to develop among chemists an interest in the polarising microscope and its applications. The wider scope of the second edition now under review suggests that the first was most successful; in fact, the excellent treatment of more advanced subject matter shows that the optical method has indeed found many chemical applications. Some parts of the book should be recommended reading for

mineralogists and physicists as well as for the chemists for whom the book was written.

The scope of the volume may be noted from the contents paraphrased as follows: ideal and real crystal structures, forms, and chemical constitution; stereographic projection; crystal morphology; crystal optics, polarising microscope; preparation of materials; systematic examination of material and presentation of results; and finally, chapters on liquid crystals, single and double variation methods, universal stage, and examples of the use of the microscope. The lucid treatment of the relation between crystal optics and structure is especially commended. The beginners' experiments described in pages 362 to 385 will be most helpful; it is regretted that the determination of refractive index using interference figures to check orientation is not given space among them.

HORACE WINCHELL

Selected Topics in X-ray Crystallography; J. BOUMAN, Editor. Monographs on Theoretical and Applied Physics from the Delft X-ray Institutes, Vol. III. Pp. xv, 375; illustrated. Amsterdam and New York, 1951 (North-Holland Publishing Co., and Interscience Publishers, Inc., $11.00).—Dr. Bouman's editorship has brought forth an important symposium on certain subjects in X-ray crystallography. The preface states that this volume is a series of partly interrelated monographs bearing on several applications of X-ray diffraction, of special interest in physics, chemistry, and mineralogy. The applications have been based largely upon the concept of an ideal lattice structure; to this concept corrections are made for the deviations occuring in real crystals. The book is divided into eight main parts, each containing from one to five chapters written, in general, by different authors on subjects pertaining to their special researches at one of the X-ray laboratories at the Technical University of Delft during and after the war.

The titles of the eight major parts may be paraphrased as follows: A) General methods, structure analysis; B) Distortions in crystals; C) Stimulated crystals, twinning, and nucleation; D) Photographic emulsions and silver halide crystals; E) Amorphous state; F) Quantitative work; G) Rubber; H) Biological work. The several monographs are thus arranged so as to permit the reading of any single major part separately, except that part B depends closely upon A.

There can be no doubt of the value of this volume in laboratories doing work on the structure of matter in the solid state. Even in cases where no chapter title would show explicitly a relation to a given field, the chances are that theoretical and practical

aid could be derived from a study of part A. The principal deterrent for many workers will be the high cost of the book, which will undoubtedly (and regrettably) reduce its circulation.

HORACE WINCHELL

PUBLICATIONS RECENTLY RECEIVED

U. S. Geological Survey Water-Supply Papers, as follows: 1050, Quality of the Surface Waters of the United States, 1946—$1.25; 1104, Quality of Water of the Gila River Basin above Coolidge Dam, Arizona—$1.00; 1113, Surface Water Supply of the United States, 1948, Part 3, Ohio River Basin—$1.75; 1115, Part 5, Hudson Bay and Upper Mississippi River Basin—$1.25; 1118, Part 8, Western Gulf of Mexico Basins—$1.00; 1124, Part 14, Pacific Slope Basins in Oregon and Lower Columbia River Basin.—Washington, 1950, 1951.

U. S. Geological Survey Bulletins, as follows: 955-D, Gold Placers and Their Geologic Environment in Northwestern Park County, Colorado—$1.25; 962-D, Tin Deposits of Durango, Mexico; 963-D, Photo Interpretation of the Terrain along the Southern Part of the Alaska Highway—$.55; 964-D, Geology and Mineral Resources of the Maimón-Hatillo District, Dominican Republic—$.75; 964-E, Quicksilver Deposits of Chile—$.75; 969-A, Diamond-Drill Exploration of the Dillsburg Magnetite Deposits, York County, Pennsylvania—$.70; 969-B, Corundum Deposits of Gallatin and Madison Counties, Montana—$.75; 969-D, The Blewett Iron-Nickel Deposit, Chelan County, Washington—$.65; 974-C, Frost Action and Vegetation Patterns on Seward Peninsula, Alaska—$.40; 976-D, Geophysical Abstracts 143, October-December 1950—$.20. Washington, 1950, 1951.

U. S. Geological Survey Professional Papers, as follows: 221-E, Geology of the Fort Smith District, Arkansas—$1.00; Pleistocene Shore Lines in Florida and Georgia—$1.00; 221-H, The Habits and Adaptation of the Oligocene Saber Tooth Carnivore, *Hoplophoneus*—$.40; 229. Mica and Beryl Pegmatites in Idaho and Montana—$1.50. Washington, 1950.

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Handbook of Experimental Psychology; edited by S. S. Stevens. New York, 1951 (John Wiley & Sons, Inc., $15.00).

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